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MEASUREMENT OF CHARACTERISTICS
OF LIGHTNING AT HIGH ALTITUDES

Centre d'Essais Aeronautique de Toulouse

Translation of "Mesure des caracteristiques de la foudre en altitude",
Centre d'Essais Aeronautique de Toulouse, Toulouse, France, Test No.
76/650000 P. 4, May, 1979, 74 pages.

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TABLE OF CONTENTS

| | |
|--|----|
| 1. Introduction..... | 1 |
| 2. Testing Program..... | 2 |
| 3. Testing Facility..... | 3 |
| 4. Testing Equipment..... | 4 |
| 5. Safety..... | 8 |
| 6. Distribution of Tasks..... | 8 |
| 7. Results and Interpretation of Measurements..... | 9 |
| 8. Conclusion..... | 18 |

PLATES

| | |
|--|----------|
| 1-6 Measurement Circuitry..... | 20-25 |
| 7,8,10 Transall Layout..... | 26,27,29 |
| 9 Video Recorder Passband..... | 28 |
| 11-16 CEV Flight Report..... | 30-41 |
| 17 Photographs of Measuring Rods..... | 42 |
| 18-37 Lightning Bolt Current..... | 43-62 |
| 38-51 Test Circuit..... | 63-76 |
| 52 Voltage V_i Induced on the Test Line as a Function of the Peak Value of the Lightning Bolt Current I_F | 77 |

MEASUREMENT OF CHARACTERISTICS
OF LIGHTNING AT HIGH ALTITUDES

Centre d'Essais Aeronautique de Toulouse (CEAT)
23, Avenue Henri Guillaumet, 31056 Toulouse cedex, France

Test Request No.: 2120 STA-Eq, Oct. 28, 1976

Recorded at CEAT on Nov. 4, 1976

As No. 24,141

Tests Begun on May 18, 1978

Tests Ended on July 17, 1978

Summary

The report contained herein gives the results of the measurement of lightning characteristics made in flight with the aid of a specially equipped Transall airplane during the 1978 series of tests.

1. Introduction

/11*

New developments in aeronautical technology -- the use of composite materials, new electronic components, electric flight controls -- have made aircraft potentially more and more vulnerable to the effects of lightning. The safety of air flights is therefore now in question.

So as to be able to both evaluate the risks incurred by the new generations of aircraft and enact recommendations, if not specifications or standards, two technical agencies, the STA and the STTA, decided to conduct a series of measurements of lightning characteristics at elevated altitudes. They called on the CEV, SEFTIM, CESTA, SNIAS, the AIA at Clermont-Ferrand, and CEAT.

The fourth and final memorandum on the tests, which is

*Numbers in the margin indicate pagination in the foreign text.

contained herein, reports the results of the 1978 in-flight measurements made with a Transall C 160-04 airplane owned by CEV-Bretigny.

The partial reports making up Memorandum 650000 cover the following areas:

- report 1: tests of the strength of the measuring rods for the C 160;
- report 2: the final acceptance of the shielded, air transportable ^{enclosure} casing;
- report 3: acceptance trials: the optical lightning sensors and the time signal distributors.

2. Testing Program

There were two phases to the tests:

- 1) Ground-based tests of lightning strikes, which were conducted to debug and calibrate the measurement facilities.
- 2) In-flight tests of lightning strikes, which had three objectives:
 - to evaluate the current in a bolt of lightning;
 - to measure the voltage surge in the onboard circuitry and in certain pieces of equipment;
 - to document the relationship between lightning bolt current and the voltage surge so as to develop a theoretical model and thus to become acquainted with the significant parameters.

The program was elaborated in the following documents:

In-Flight Lightning Tests

- DRME meeting of June 19, 1975 -- decision to measure the characteristics of lightning at high altitudes;
- CEAT meeting of August 27, 1975 -- development of the testing program;
- STA-Eq test request of December 8, 1975 -- to CEV-Bretigny;
- CEAT note of June 10, 1976 -- finalization of the testing program;
- CEV note to the STA -- equipping the Transall A04 for the lightning bolt tests.

Ground-Based Lightning Bolt Tests

/12

- CEAT meeting of December 6, 1977;
 - CEV-Cazaux meeting of December 20, 1977
 - CEAT meeting of January 18, 1978
 - CEV-Cazaux meeting of March 2, 1978
- } elaboration of ground-based testing program
- CEV note to the STA, no. 4630, of April 18, 1978
Study of lightning strikes -- testing program for the C 160 - A 04

3. Testing Facility

In consideration of the very particular character of the tests, the airplane decided upon was a Transall C 160-04 owned by CEV-Bretigny. The principal reasons for this choice were the following:

- availability of the aircraft;
- the aircraft's safety: the reports of lightning striking Transalls in formation show their low vulnerability to

lightning;

- the aircraft's slowness: 170 knots in turbulent conditions (the low speed helps to minimize the effects of multiple lightning strikes sweeping the vehicle);
- the airplane is equipped with weather radar;
- the Transall is a cargo plane capable of carrying the ^{enclosure} casing that contains all the recording equipment.

4. Testing Equipment

4.1 Measurement of Lightning Bolt Current (Plate 1)

Lightning bolt current was measured with two 1 mohm coaxial shunts having a response time of 80 ns. Each shunt was placed inside a 4 m long thin pole, one inserted into the front of the airplane and the other into the rear of the fuselage. The poles acted as lightning rods.

4.2 Magnetic Field (Plate 2)

The magnetic field was measured at four points on the airplane (one on each of the wings' leading edges, two on the fuselage) by means of three-axis sensors with a time constant $\tau = 1 \mu s$.

4.3 Voltage Surges in Electrical Networks (Plate 3)

Voltage surges in three networks were measured:

- 28 VDC,
- 115 VAC, variable frequency,
- 115 VAC, 400 Hz,

with the aid of optical fiber measurement circuits whose response

curve is given in plate 4.

4.4 Voltage Surges in the Equipment (Plate 5)

/13

Voltage surges at the terminals of the following equipment:

- a position light,
- a copilot's window defroster,
- the anemometric antenna heater,
- the fuel flow indicator,
- the weather radar,
- a VHF,
- a VOR

were measured by lines which were electrically isolated from the equipment by optical coupling.

4.5 Test Line (Plate 6)

The test line was a 5 m long wire placed inside the fuselage, 0.22 m from the airplane's skin. This circuit was used to study the coupling between the lightning bolt current and airplane wiring, which the wire simulated.

4.6 Skin Current

Skin currents were measured with "Mobius" loops (a magnetic loop insensitive to the electric field). Four loops were mounted in pairs, one on the outside and the other on the inside of the fuselage, slightly in front of the plane of the propellers.

These sensors, sensitive to the tangential magnetic field in the vicinity of the airplane's skin, gave an indication of the surface current density. The devices are described in detail in SEFTIM's Bulletin 3635 (order no. 77/86025/00481 75 88).

4.7 Flash Sensor

The flash sensor is a photoelectric cell that produces a signal when it is subjected to intense illumination, such as a flash of lightning.

This signal, after suitable transformation, served to mark the times lightning struck on the recording equipment. A detailed description of the system can be found in SEFTIM's bulletin 33508 of September 1977.

Plates 7 and 8 give an overall view of the special measurement equipment used in describing lightning bolts and their indirect effects.

4.8 Recording

/14

The measurement and the recording of subtransitory signals in environmental conditions that are particularly perturbed from the electromagnetic point of view is a very difficult problem. It was resolved by respecting the following two rules:

- The measurement lines connected to the recording equipment only touched a single point on the airplane's mass.

- All the recorders were placed inside a Faraday cage (measurement casing) that attenuated the electrical field by at least 100 dB up to frequency of 30 MHz and by at least 50 dB up to 100 MHz. (See CEAT Memorandum 650000, second partial report.) The measurement casing was connected to the airplane at only one point.

The following two additional constraints were added to the problem of immunity to outside perturbations:

- recorder passband (2 MHz);

- the longest possible recording time, since a lightning bolt is not a predictable event.

The following solution was adopted:

- Three Sony AV 3670 CE video recorders (modified mechanically and electrically) for recording two lightning bolt currents and the test circuit (one hour and 15 minutes of playing time, passband represented on plate 9).
- One Schlumberger ME 4050 recorder (10 minutes of playing time, a 2 MHz passband for direct input, a 400 kHz one for frequency modulation).
- One Tolana A 4661 recorder (10 minutes of playing time, 400 kHz passband for direct input, 80 kHz for frequency modulation).

Plate 10 shows how the measurement channels were divided up among the recorders.

The recorders were synchronized by an Edith time base owned by CEV-Bretigny.

Besides these specific pieces of equipment for measuring and recording lightning bolt current and its indirect effects, the airplane's own equipment was used too:

- radio equipment for recording parasitic signals in the radio frequency range;
- various indicators for recording flight parameters on the airplane's black box recorder.

A description of how the Transall's equipment was arranged is given in CEV-Bretigny's Memorandum 2448 of February 26, 1979.

The following precautions were taken to ensure maximum safety:

- an unbroken metal coating over the entire structure;
- verification of the mechanical strength of all the pieces of equipment in use (measurement casing, rods, etc.);
- special protection for the fuel tank caps.

6. Distribution of Tasks

Under the leadership of the two technical agencies, the STA and the STTA, the various jobs were parcelled out as follows:

- AIA of Clermont-Ferrand: Adaptation of the airplane (insertion of measuring rods, development of protective devices for fuel tank caps, installation of measurement lines).
- SEFTIM: Study and development of skin current sensors, flash sensors, and time base transmission line, participation in ground-based tests at Cazaux, analysis of results.
- CESTA: Study and performance of ground-based tests at Cazaux.
- CEV: Measurement line inspections, installation of optical fibers, performance of tests, measurement data processing.
- SNIAS: Development and installation of carbon fiber wing tip.
- CEAT: Elaboration of overall program; study, development, perfection of measurement lines; wiring for measurement casing; testing and acceptance of equipment, partial processing and interpretation of measurement data.

7. Results and Interpretation of Measurements

7.1 Ground-Based Tests

The attempt to get lightning to strike the ground-based instruments at Cazaux ended in failure. SEFTIM's Report no. 4334 describes the partial calibration tests performed during the observation period.

7.2 In-Flight Tests

During seven flights (17 hours) to investigate stormy conditions, lightning struck the airplane nineteen times. Fourteen of those episodes were recorded.

7.2.1 Conditions under which Lightning Struck

/16

The following conditions existed when a discharge of lightning through the airplane was obtained:

- flight level: 100-150
- temperature: -5°C to 0°C
- type of clouds: cumulonimbus, isolated or in clusters
- precipitation: generally hail ~~hail~~
- turbulence: generally average
- nature of discharge striking airplane: on the edge of or inside the cloud (one or two nautical)
- appearance of lightning: forked except for one case of ball lightning

Plates 11 to 16 give a detailed description of each of the flights.

7.2.2 Structural Damage

7.2.2.1 Carbon Fiber Wing Tip

During flight no. 5, the carbon fiber wing tip developed by SNIAS was punctured. Expert examination, first by SNIAS and then by CEAT, concluded with the finding that a hailstone had punctured the tip. (There was no trace of burning around the hole.)

7.2.2.2 Front Measuring Rod and Aircraft Structure

The front rod, as well as the sheathing on the forward part of the airplane, suffered multiple hits by one bolt of lightning. The points of impact were spaced about 30 cm apart (photograph on plate 17).

The pits on the rod generally had a diameter of 2 to 3 mm and a depth of a few tenths of a millimeter.

7.2.2.3 Rear Rod

A single lightning bolt never struck the rear rod more than once. The tip alone was melted. This result shows that the arc was "drawn out". The phenomenon, which is common on all aircraft, confirms that only the rear part of the structure risks absorbing an integral transfer of lightning energy (plate 17) while the front part of the airplane only suffers multiple discharges sweeping it.

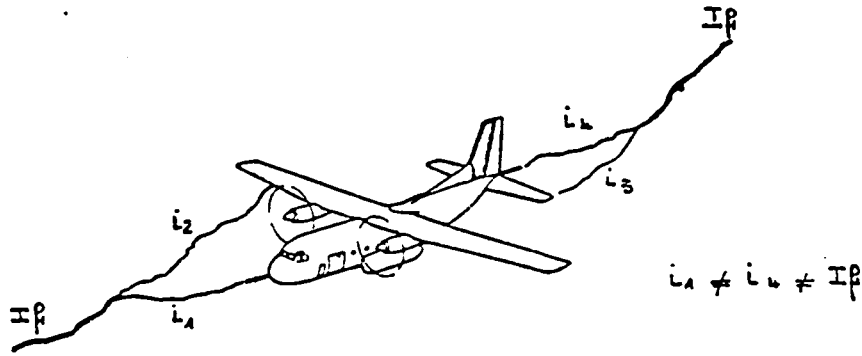
7.2.3 Lightning Bolt Current

/17

7.2.3.1 Current in Front and Rear Poles

The peak currents recorded in the front and rear poles differed in certain cases by a factor of three even though qualitatively (ascent time, time from zero to I_{max} , descent time) they were identical.

This phenomenon stems from the fact that a flash of lightning has several branches, but only one of them passes through the rod:



7.2.3.2 Description of Lightning Bolt Current

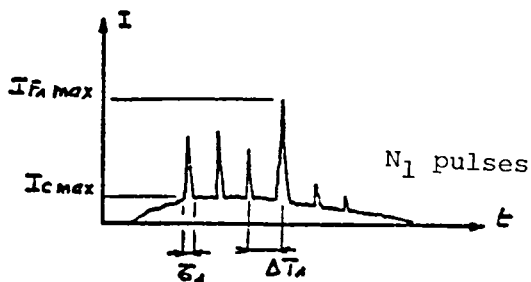
Plate 18 summarizes the results.

Each of the recordings is presented in detail on plates 19 to 34.

The following analysis only takes the results for the front rod into account, i.e. thirteen recordings.

Three typical forms are distinguishable:

Type 1 Lightning Bolt Current (Total Number: 6)



The current takes the form of a group of N_1 pulses of duration τ_1 and separated by an interval ΔT_1 . They are superimposed on a small DC component of amplitude $I_{c \max}$.

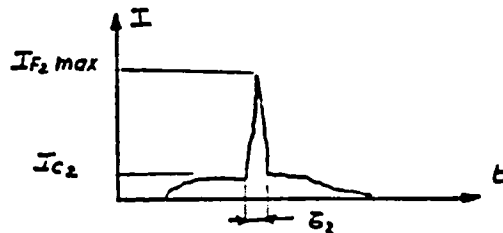
Plate 19 shows a typical lightning discharge of this type.

$$\begin{aligned} I_{f1 \max} &\leq 4.5 \text{ ka} \\ 3 &< N_1 < 12 \\ 8 \text{ } \mu\text{s} &< \tau_1 < 200 \text{ } \mu\text{s} \end{aligned}$$

$$50 \mu s < \Delta T_1 < 200 \mu s, \text{ or } 5 \text{ kHz} < f_1 (\Delta T_1) < 20 \text{ kHz}$$

$$I_{c \text{ max}} < 2 \text{ ka}$$

Type 2 Lightning Bolt Current (Total Number: 3)



The current takes the form of a single pulse^{se} of duration τ_2 superimposed on a DC component.

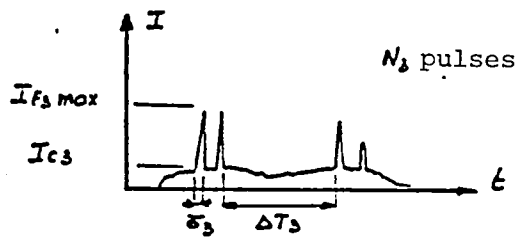
$$I_{f2 \text{ max}} \leq 70 \text{ ka}$$

$$I_{c2 \text{ max}} \leq 0.5 \text{ ka}$$

$$80 \mu s < \tau_2 < 200 \mu s$$

Plate 21 shows a typical lightning discharge of this type.

Type 3 Lightning Bolt Current (Total Number: 4)



The current takes the form of groups of pulses separated by a relatively large interval ΔT_3 .

$$1 < N_3 < 8$$

$$I_{f3 \text{ max}} \leq 50 \text{ ka}$$

$$20 \mu s < \tau_3 < 200 \mu s$$

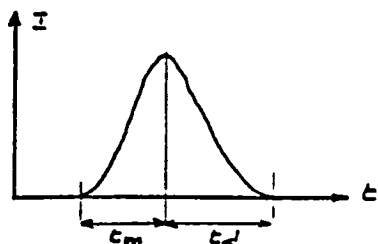
$$50 \mu s < \Delta T_3 < 14 \text{ ms}$$

A typical discharge is on plate 29.

7.2.3.3 Statistical Study of Lightning Bolt Current

Total Duration of the Phenomenon

Plate 35 shows that in 50% of the cases the total duration of the phenomenon was less than 5 ms. The maximum recorded duration was 16 ms.



The pulses take the form of a practically symmetric double exponential curve. In the majority of cases $t_m \neq t_d$.

$$8 \leq \frac{t_m}{t_d} \leq 100 \mu s$$

Maximum Amplitude of Lightning Bolt Current

Plate number 35 shows that in 50% of the cases the maximum current was ≤ 10 ka. The maximum recorded value was 70 ka.

Charge Transfer $\int i dt$

Plate no. 35 shows that in 50% of the cases, less than 6 coulombs of charge was transferred. The maximum recorded charge transfer was 10 coulombs.

Action Integral $\int i^2 dt$

The evaluation of the action integral by a linear approximation of the current form leads to a maximum of $0.15 \times 10^6 \text{ a}^2\text{-sec}$ for flight no. 11 (15:43:30).

Rate of Ascent dI/dt

Plate no. 36 shows that in 50% of the cases the maximum rate of ascent $dI/dt \text{ max} \leq 0.5 \text{ ka}/\mu s$. The max recorded value was $26 \text{ ka}/\mu s$.

7.2.4 Magnetic Field

The Me 4050 recorder functioned so poorly that it was impossible to record the whole set of magnetic field parameters. Only the transverse magnetic field on the wings' leading edges was recorded.

The only signal, quantitatively unusable, was recorded during flight 10. It appeared only on the left wing sensor.

7.2.5 Skin Current

The results show, at least for flight 10, the only usable recording, that the current density on the inside wall is zero.

This surface current, zero on the inside, confirms that for a completely metallic airplane, the shielding effect is very great. The residual interior magnetic field is therefore very weak. The smaller the openings (electromagnetic windows) are, and the more the characteristics of the structural material (thickness t , permeability μ , and resistivity ρ) and the lightning bolt frequency spectrum meet certain criteria, the more this is true. (See CEAT Study 534100, first part, technical note no. 3.)

7.2.6 Lightning Surges in the Electrical Networks

No voltage surge in the onboard electrical networks (28 VDC, 115 VAC with variable frequency, and 115 VAC at 400 Hz) was documented.

Two complementary reasons explain this result:

/21

- sensors of too low sensitivity (maximum sensitivity: 400 peak volts);
- the airplane circuitry is in fact very little perturbed (entirely metal structure, very weak residual internal magnetic field). This hypothesis is confirmed by the fact that no equipment was ruined during the test series.

7.2.7 Lightning Surges in the Equipment

No measurements could be made because the ME 4050 recorder broke down.

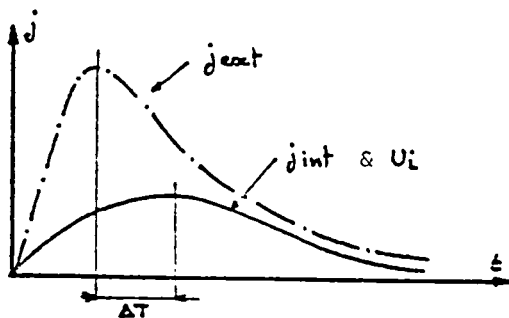
7.2.8 Test Line



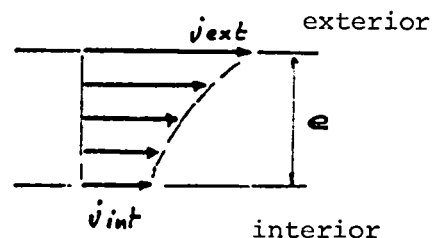
of negligible internal impedance, wiring, and a receiver with an input impedance of 50 ohms.

The voltage surge U_i at the receiver terminals is a function of the wiring characteristics (L, C, R) and of two effects:

- The effect of current diffusing across the airplane's skin. This phenomenon is expressed by an attenuation of the ascending part of the pulse, a shift in the maximum point, and a smaller current density on the internal wall than on the external one.



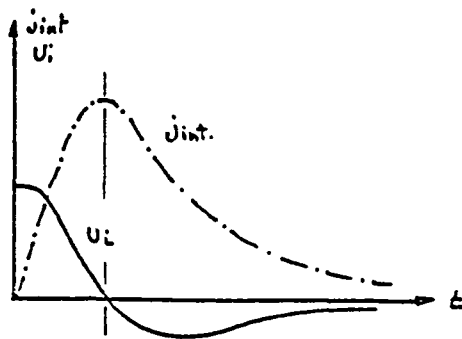
Variation in External and Internal Current Wave Form



Distribution of Current Density in an Airplane Skin of Thickness e

- The inductive effect due to the internal magnetic field. The internal magnetic field is on the one hand proportional to the derivative of the current density j_{int} on the inner wall and on the other depends on the openings (electromagnetic windows) in the aircraft structure.

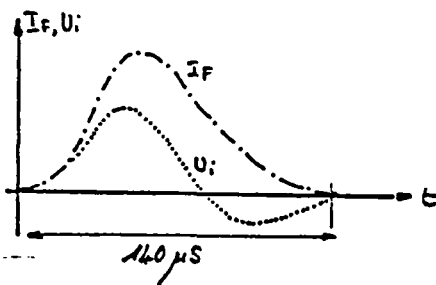
Considering the recorders' passband and size, the wiring



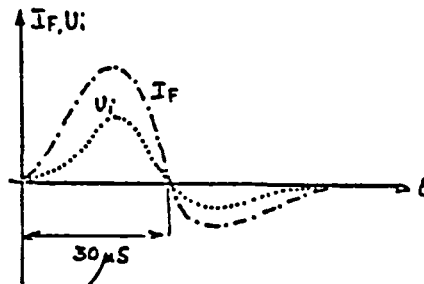
parameters, R , L , C , can be neglected for the test circuit. The measurement impedance Z_e is 50 ohms.

Examination of the oscillograms, plates 38 to 50, even though it is difficult to tell where time zero is, shows:

- that U_i lasts a shorter period of time than I_i in every case;
- that when $I_i(t)$ varies slowly, the contribution of the inductive effect (dI_i/dt) increases.



Diffusion of Little Significance
 dI/dt with Slight Delay
(Flight No. 5)



Significant Diffusion
 dI/dt Low
(Flight No. 11)

There was an almost certain correspondance during the three flights between the current measured on the rod and its effect on the test line.

/23

The table below summarizes the main characteristics of the current and the peak amplitude of the measured induced voltage V_i :

| FLIGHT | TIME | I_{max} (KA) | dI/dt (KA/ μ s) | V_i | t_m μ s |
|--------|-----------|----------------|-----------------------|-------|---------------|
| 5 | 15h42'20" | 28 | 0,6 | 13 | 70 |
| 5 | 15h43'16" | 45 | 5 | 40 | 10 |
| 10 | 17h52'11" | 50 | 1,2 | 6 | 50 |
| 10 | 17h52'11" | 33 | 1,5 | 4 | 20 |
| 11 | 15h43'30" | 70 | 35 | 8 | 15 |

- There is no obvious correlation between U_i and the parameters dI/dt and t_m .

- In contrast, in flights 10 and 11 U_i varies linearly as a function of I_{max} .

- Flight no. 5 exhibited elevated voltages that are explained neither by the form nor by the amplitude of the current collected on the front rod.

- It is difficult to support any hypothesis of linearity because of the small number of samples available.

In contrast, the current-induced voltage superposition analysis performed in plate 51 shows that the inductive effect is never dominant.

Plate 52 shows the variation in induced voltage as a function of the peak value of the current I_F .

Note:

- Two induced voltages on the test line do not correspond to any recorded lightning bolt current. In these cases, the lightning bolt current passed through neither of the measuring rods.

- The absolute value of the induced voltages U_i was

relatively low, 40 V max. This is due to the fact that the test circuit is of small size, the structural shielding effective, and the current density relatively low (large-size fuselage).

7.2.9 Radio Noise

/24

The measurement equipment worked poorly, and no recording of radio noise was possible.

8. Conclusion

The 1978 series of in-flight measurements of lightning bolt characteristics has, as a whole, shown the validity of the design of the test and measurement equipment used. The difficulties encountered during the series originated either in the problems with the recorders or in an initial overestimation of the magnitudes to be measured.

The first series supports the choices which led to the elaboration of the test equipment used, and the lessons learned give us a better idea of the performance required from the different measurement apparatus. The preparatory work for the next series of tests should concentrate on:

- the recording apparatus,
- the increased use of optical fiber transmission lines,
- the addition of new sensors (particularly for the electric field),
- the extension of the rear rod by means of a metal wire.

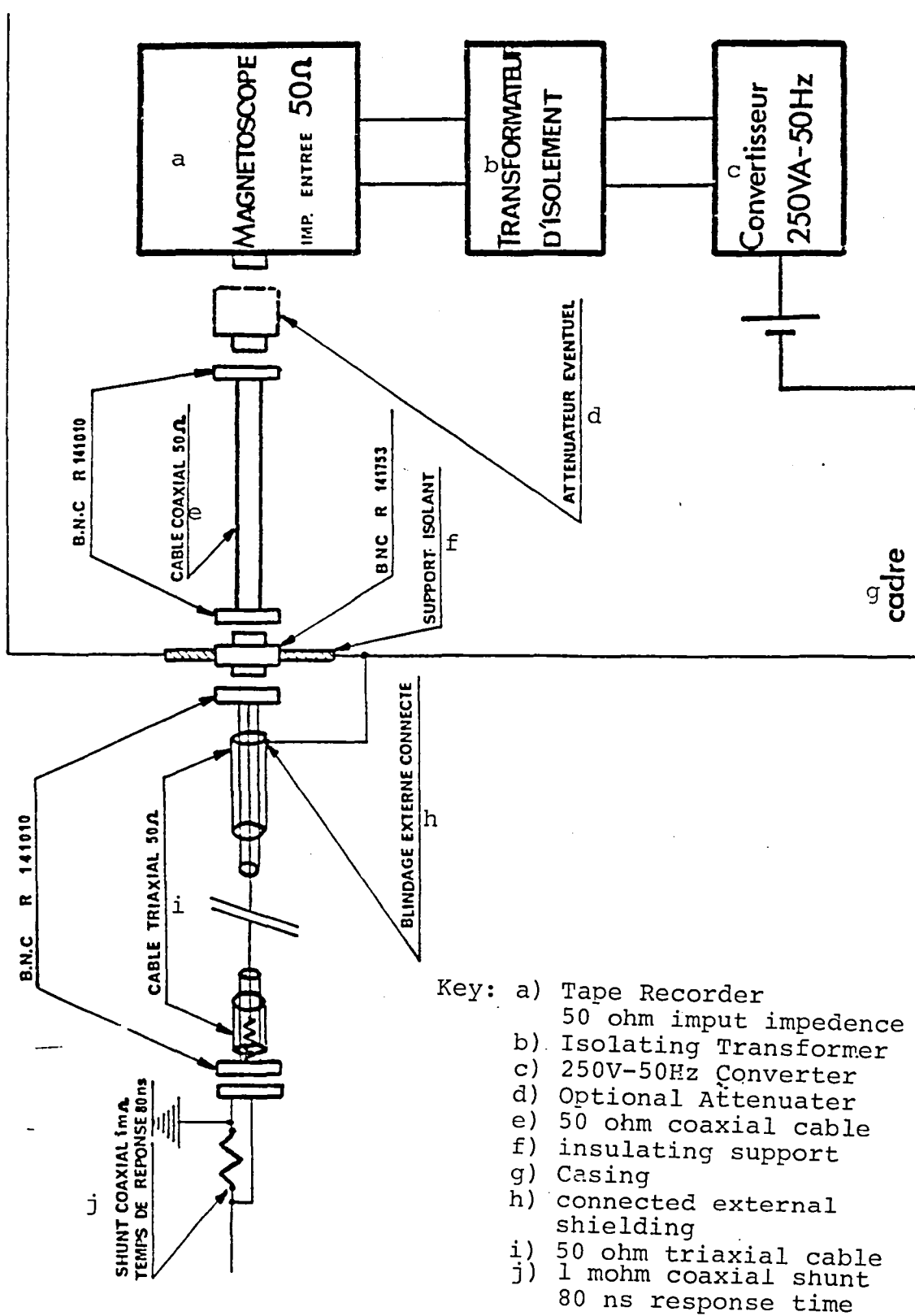
(Signed)
M. Coquelet
Group E Chief, IPA

(Signed)
D. Gall
IETA

Toulouse, May 8, 1979

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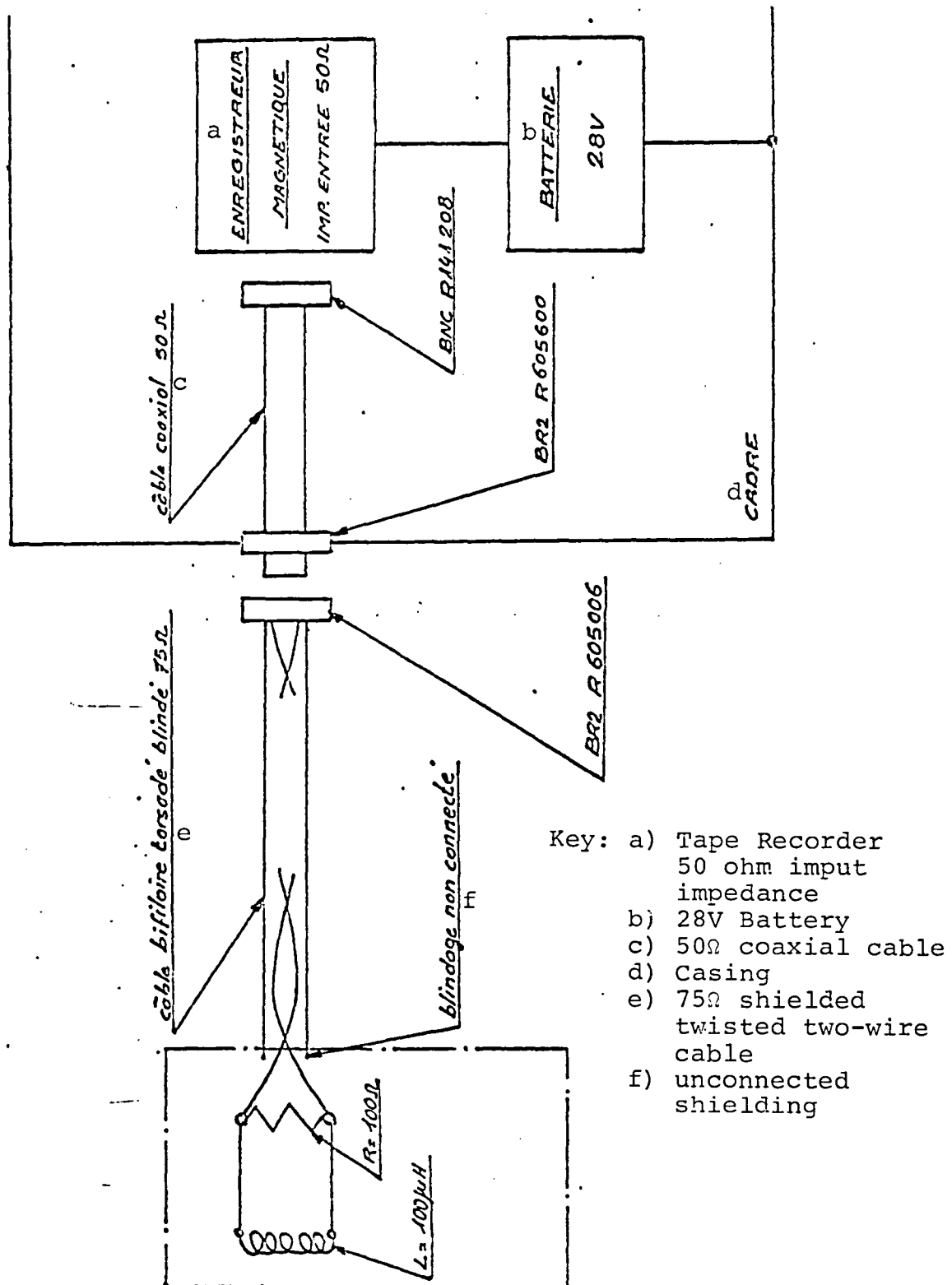
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- CEAT, "Recette definitive cadre blinde aerotransportable" [Final Acceptance of Shielded, Air Transportable Casing], Memorandum 650000, partial report 2.
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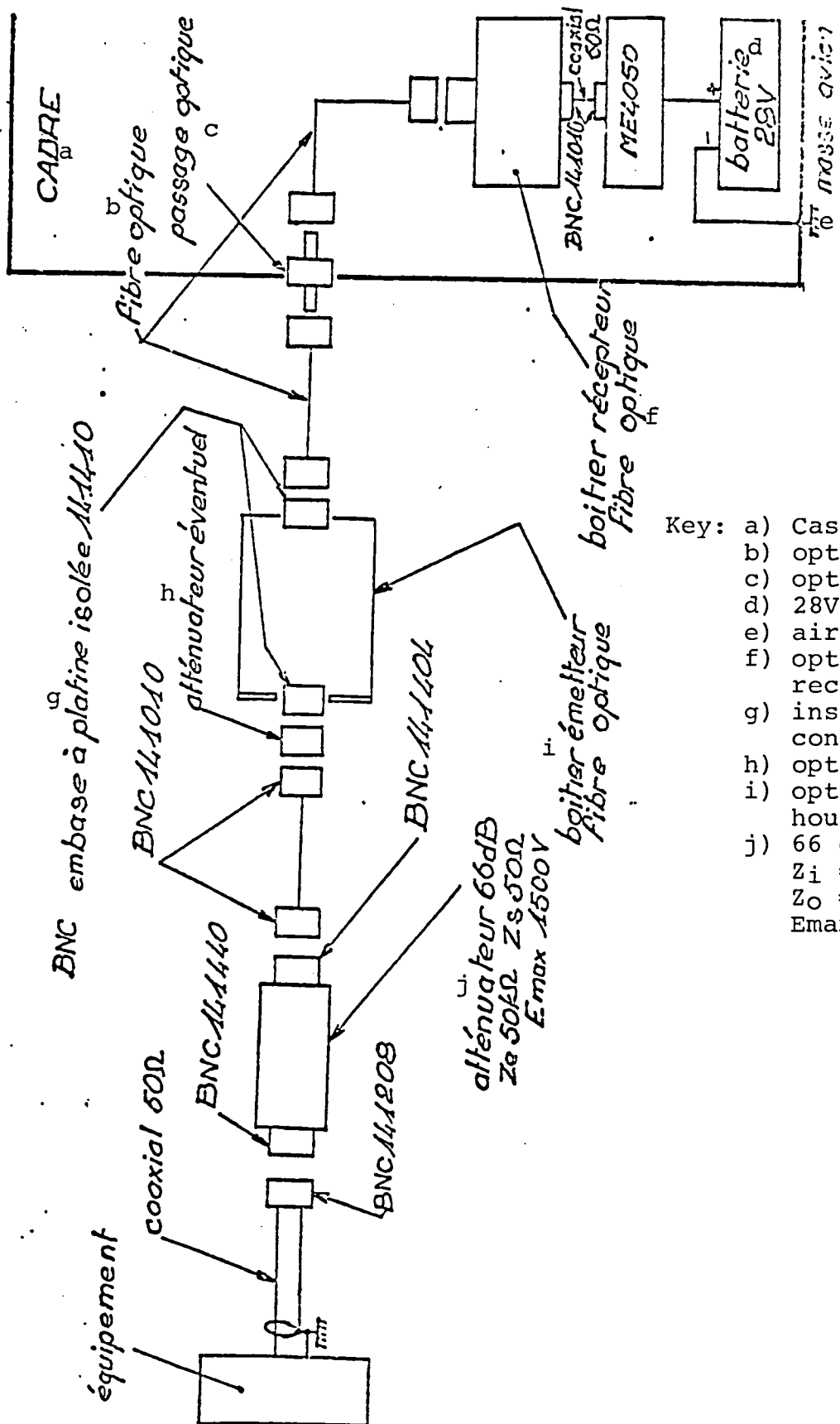


Lightning Bolt Current Measurement Circuitry

Plate 1

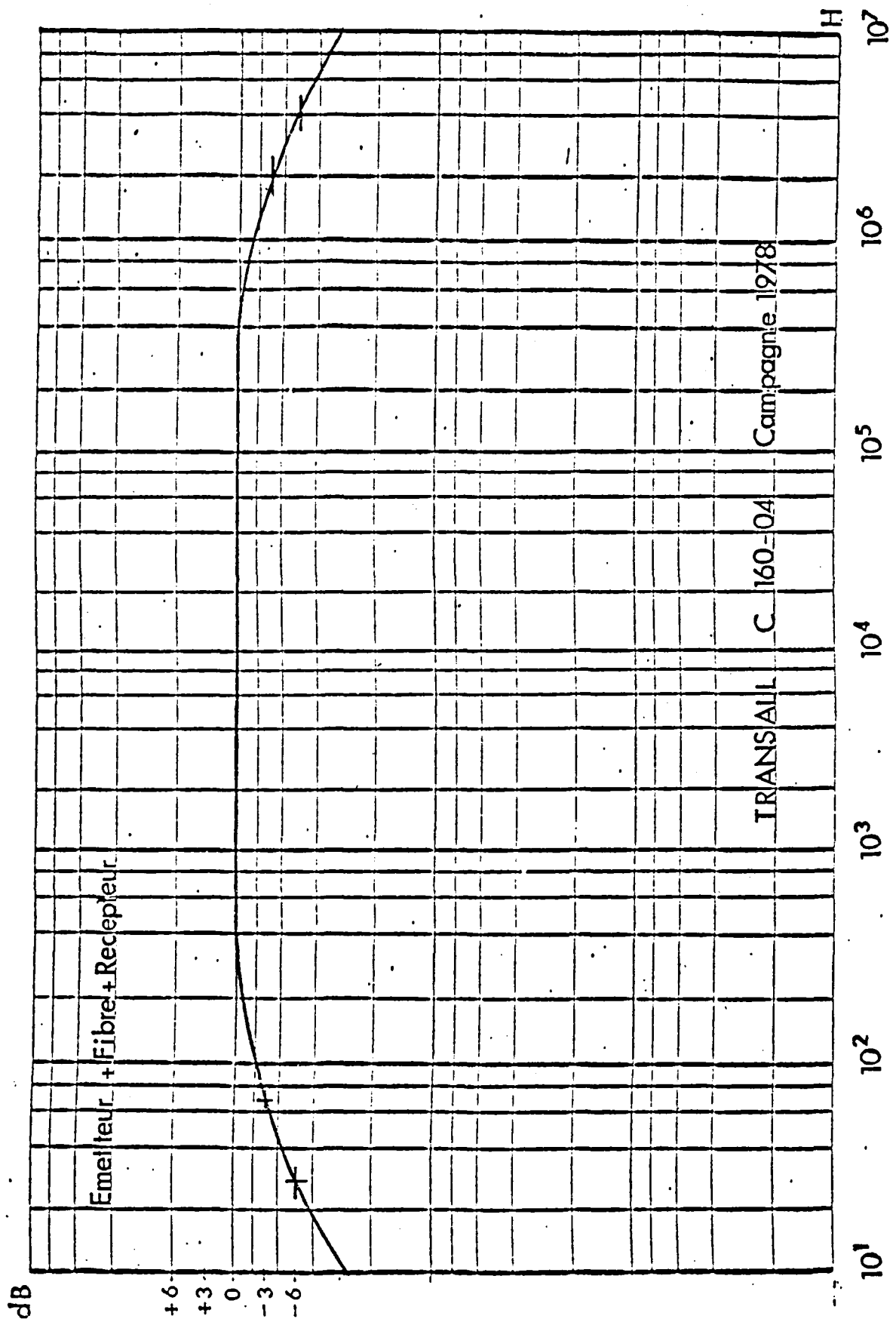
- 26 -



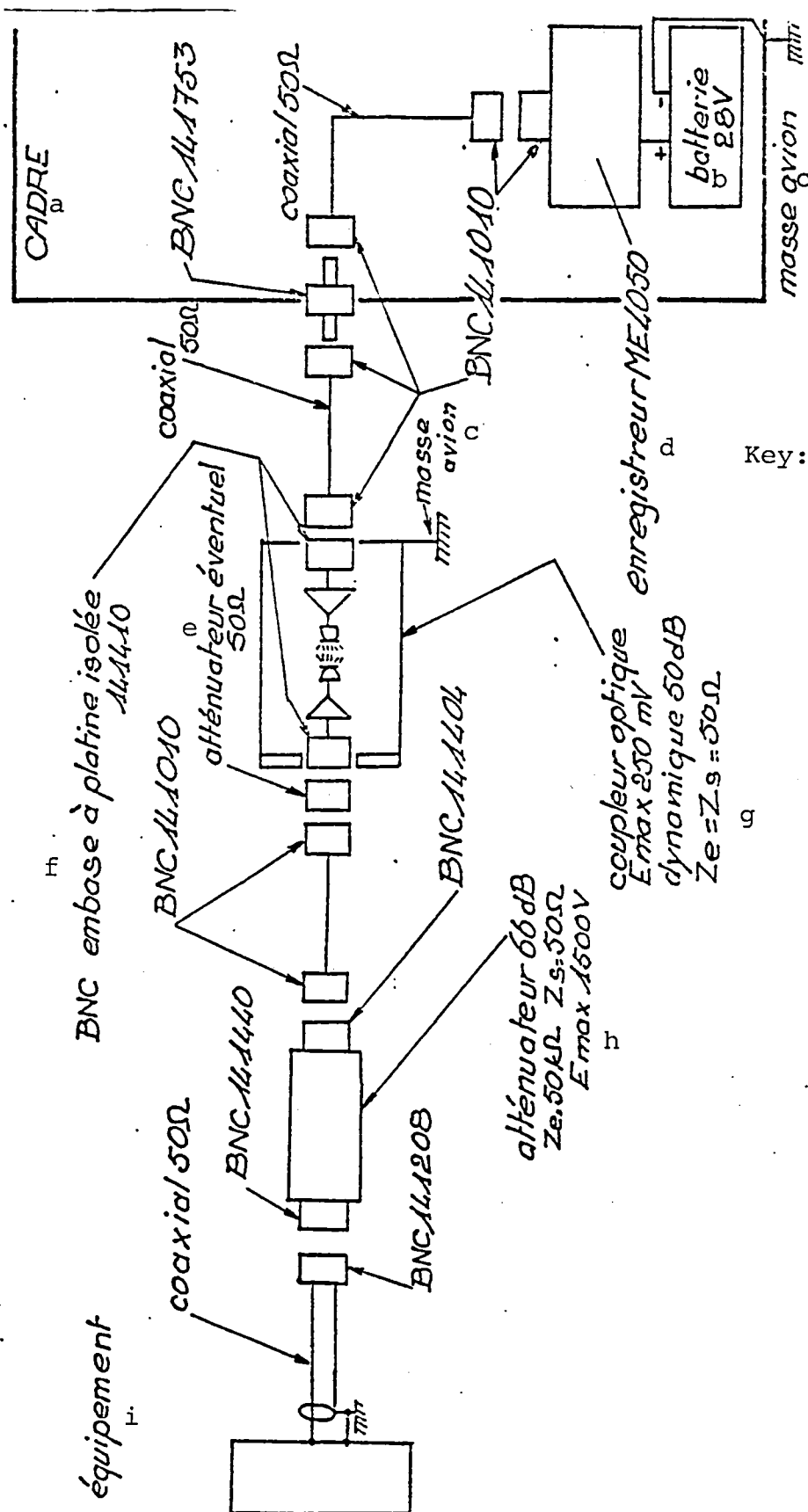


- Key:
- a) Casing
 - b) optical fiber
 - c) optical passage
 - d) 28V Battery
 - e) airplane body
 - f) optical fiber receiver housing
 - g) insulated platinum connector
 - h) optional attenuator
 - i) optical fiber emitter housing
 - j) 66 dB attenuator
 $Z_i = 50\text{ kohm}$
 $Z_o = 50\text{ ohm}$
 $E_{\text{max}} = 1500\text{ V}$

Lightning Surge Measurement by Optical Fiber



Emitter + Fiber + Receiver
1978 Transall Measurements



- Key:
- a) Casing
 - b) 28V battery
 - c) airplane body
 - d) ME4050 recorder
 - e) optional attenuator
 - f) insulated platinum connector
 - g) optical coupler
 $E_{max} = 250V$
 $50dB$ dynamic
 $Z_i = Z_o = 50 \text{ ohms}$
 - h) 66 dB attenuator
 $Z_i = 50k\Omega$ $Z_o = 50\Omega$
 $E_{max} = 1500V$
 - i) equipment

Lightning Surge Measurement by Optical Coupler

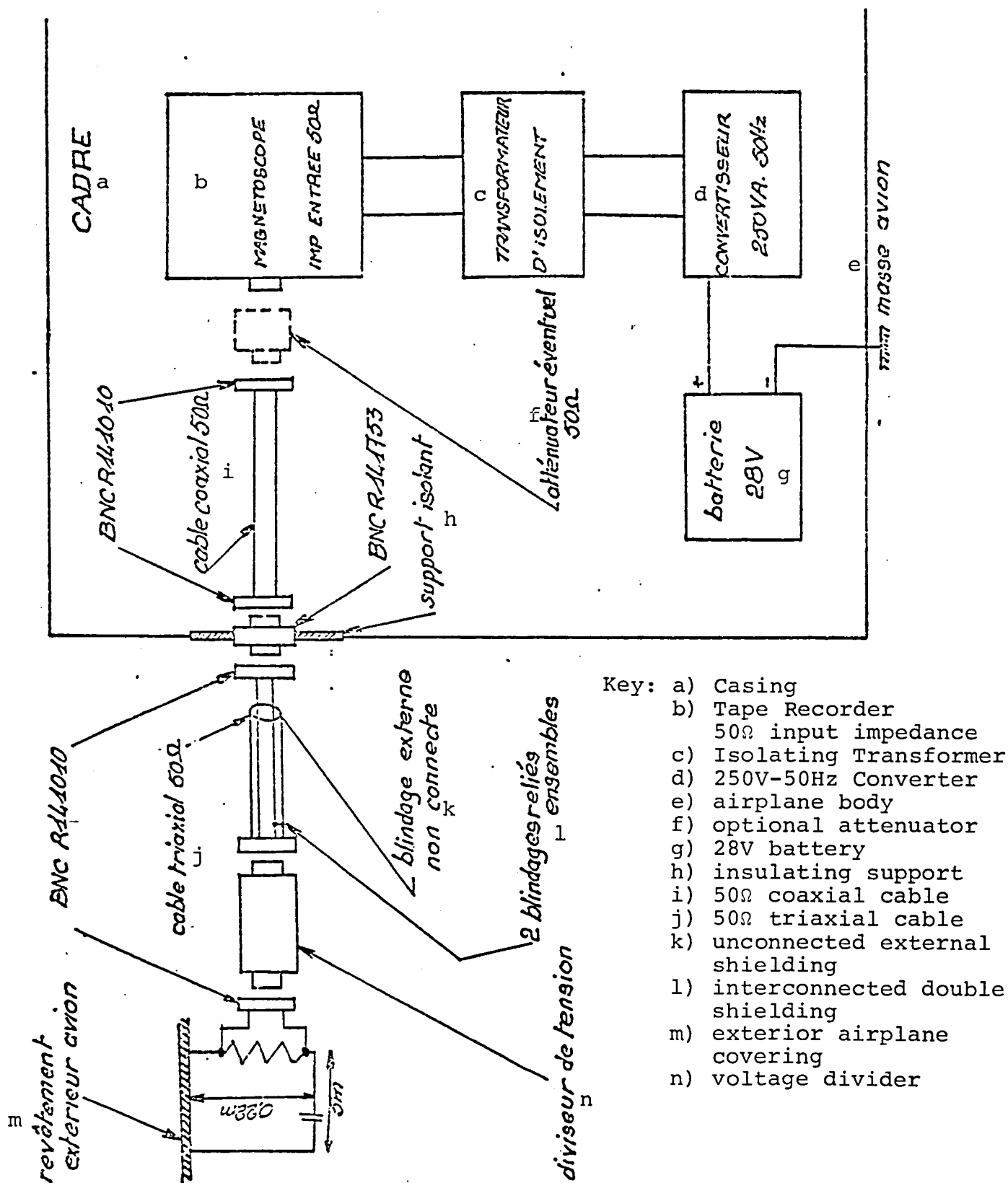
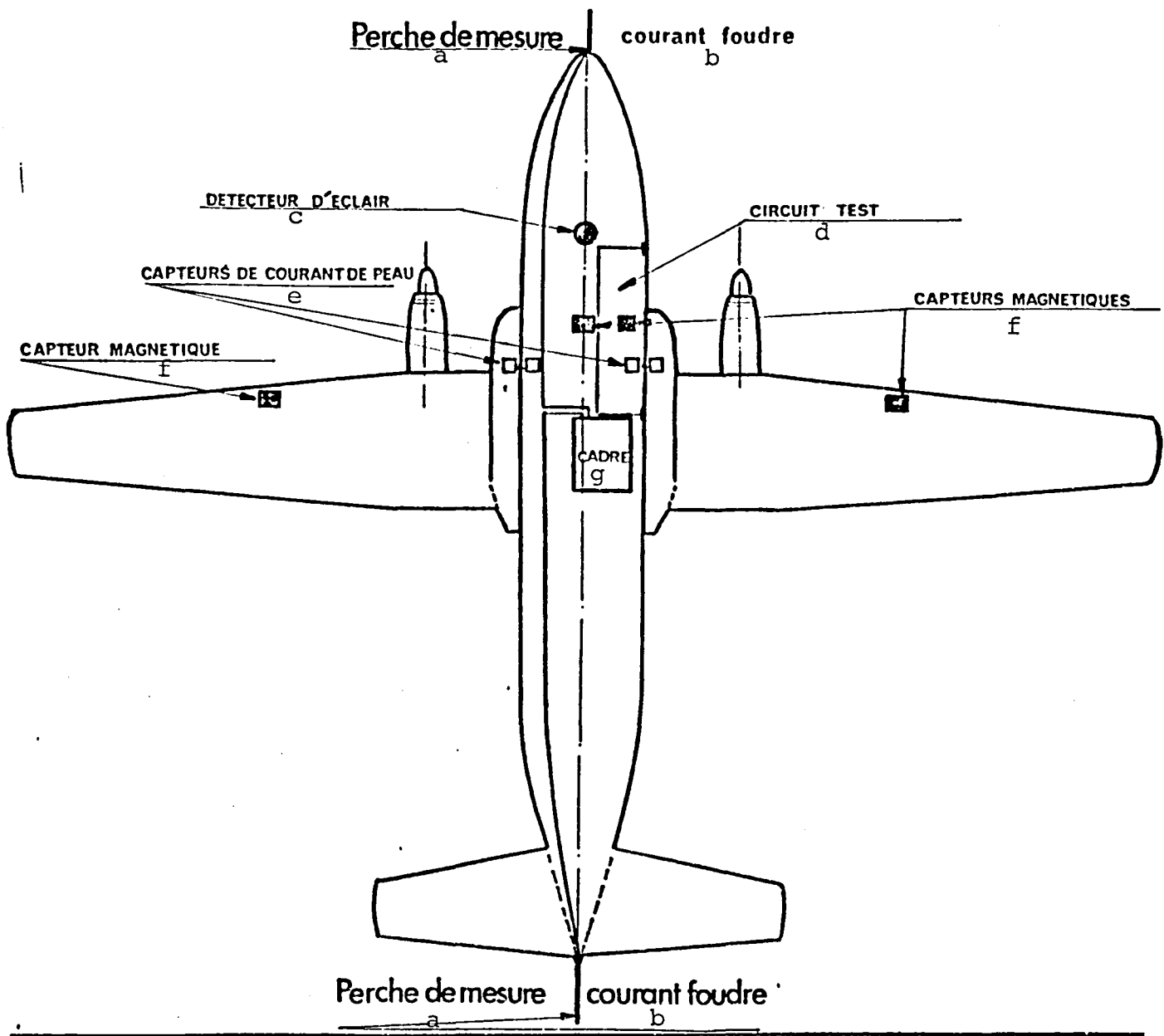


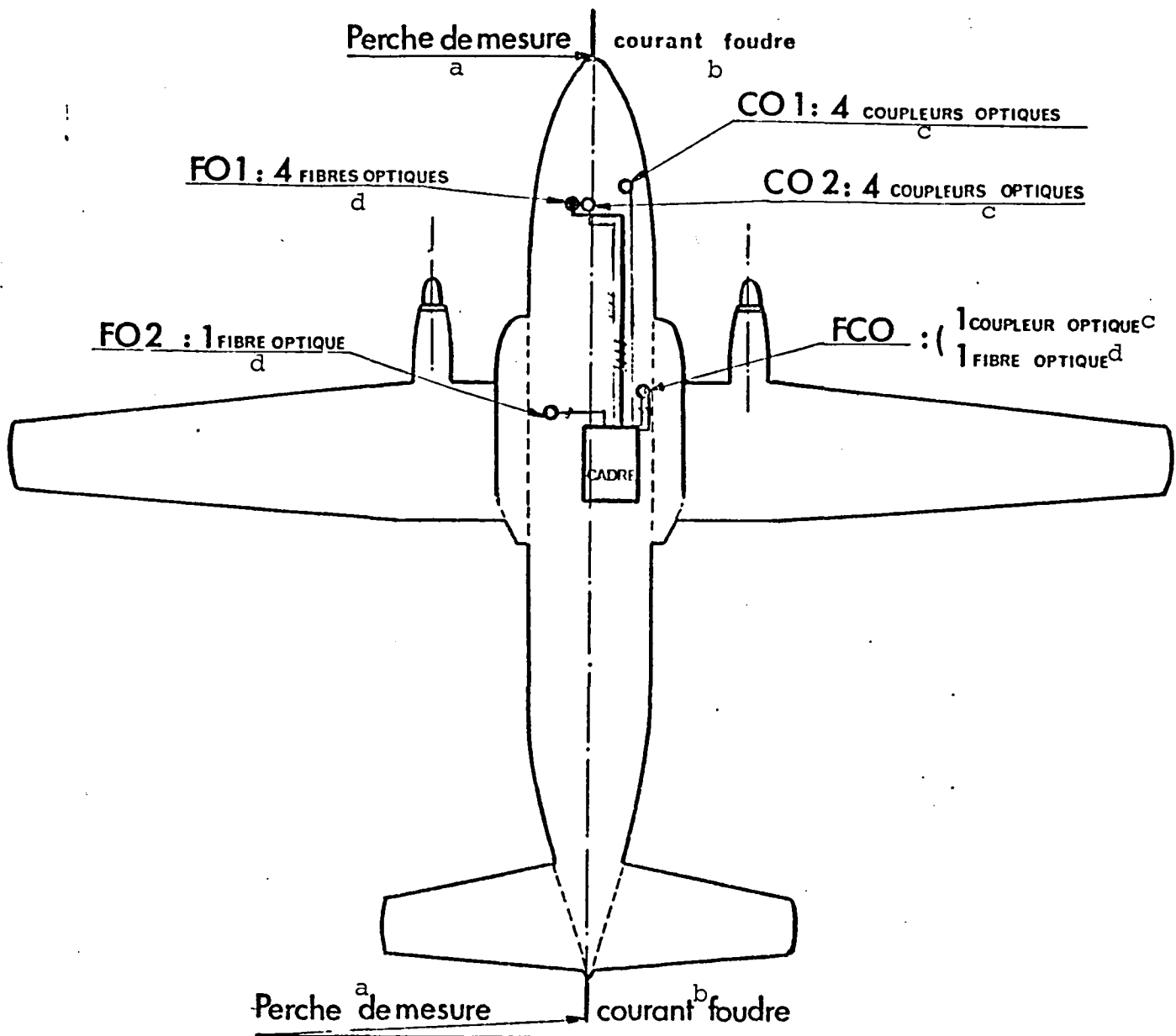
Plate 6



Description of Lightning Bolt Current

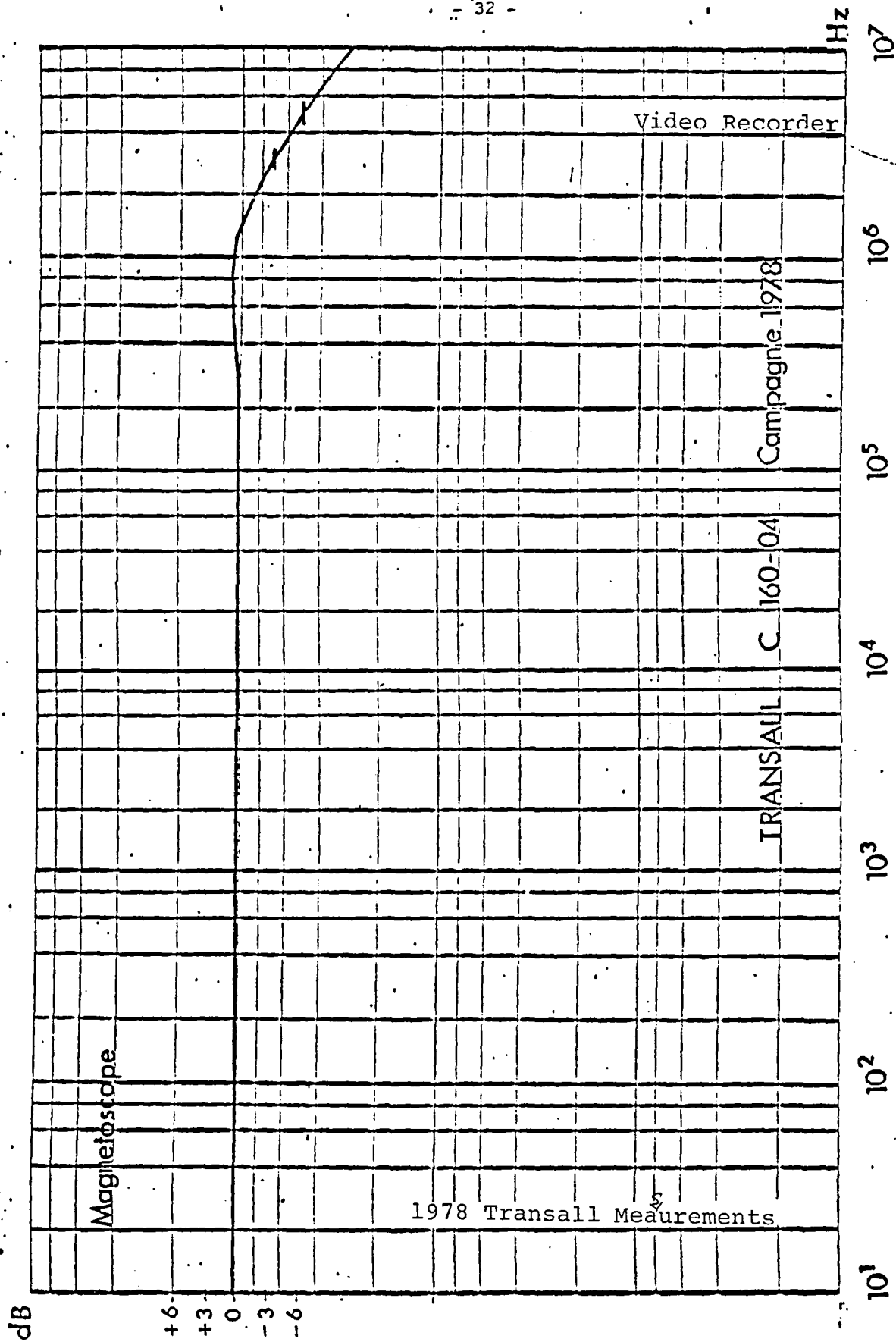
Key: a) Measuring Rod
 b) Lightning Bolt Current
 c) flash detector
 d) test circuit
 e) skin current sensor
 f) magnetic sensor
 g) shielded enclosure

Plate 7



Position of Lightning Surge Measurement Emitter Housings

Key: a) Measuring Rod
 b) Lightning Bolt Current
 c) optical coupler(s)
 d) optical fiber(s)



Measurement Panel
in Casing
Transall 160-04

29

In-Flight Lightning Test

Flight # 1, May 18, 1978

Crew: Chautemps, Tarnowski, Allenic, Gaulier, Descamp, Saint Marc

Airfield: Bretigny (for both departure and arrival)

Time of departure: 2:20 PM

Time of arrival: 4:23 PM

Ground Temperature: +17°C

Ground Pressure: 1002

Duration of flight: 2 hours 5 minutes

Time spent in stormy conditions: 15 minutes

Times lightning struck during flight: twice, on the measuring rod

Conditions and place of test:

Time (GMT): 1:37 PM and 1:48 PM

Region flown over: zone 88

Conditions of flight:

Speed: 200 knots Altitude: 10,400 ft Temperature: 0°C

Type of clouds: cumulonimbus in clusters

Precipitation: ~~hale~~ hail

Amount of turbulence: light

Weather conditions when lightning struck:

Several moments after entering the cloud

Phenomena observed before lightning struck:

Radio noise a few moments before lightning struck

What happened when lightning struck:

Flash on the front rod. The only thing the crew noticed was a thud near the copilot's feet.

Lightning-caused damage observed in flight:

None

Findings:

Since the recording system was not operating, it would be difficult

to draw any conclusions from this, the first, flight.

In-Flight Lightning Test

Flight # 5, June 2, 1978

Crew: Chautemps, Plessier, Descamps, Haguet, Allenic, St. Marc, Gaullier, Rennesson, Coquemar

Airfield: Bretigny (for both departure and arrival)

Time of departure: 2:14 PM Time of arrival: 4:40 PM

Ground temperature: 23°C

Ground pressure: 1022 (departure) 1021 (arrival)

Wind: 300/10

Duration of flight: 2 hours 30 minutes

Time spent in stormy conditions: 40 minutes

Times lightning struck during flight: 4 probable, 11 certain --
seen by the pilot

Conditions and place of test:

Time (GMT): 1 PM

Region flown over: the hills of the Perche

Conditions of flight:

Speed: 180 Altitude: 10,000 Temperature: -2°C

Type of clouds: isolated cumulonimbus

Amount of turbulence: moderate to strong

Weather conditions when lightning struck:

Isolated cumulonimbus, approximately 6 to 12 nautical miles in diameter. Cumulonimbus entered at midheight. Much hail in cloud, but little precipitation at moment lightning struck.

Phenomena observed before lightning struck:

None -- little radio noise before lightning struck.

What happened when lightning struck:

Lightning discharge on rod with thud near copilot's feet that resembled someone kicking a piece of sheet metal.

Lightning-caused damage observed in flight:

None in flight. On the ground: the fiber wing tip was punctured and the steering gear had a 5 mm diameter hole in it, with 2 [?] impacts (right side [illegible word] fillet on the horizontal stabilizer).

Findings:

A few lightning discharges hit the rod, which seemed to play the role of lightning rod well. In general, lightning struck as the cumulonimbus was entered or about 1 to 2 nautical miles from the edge. The most disagreeable thing was the ^{hail} ~~hail~~, which is what caused the damage.

In-Flight Lightning Test

Flight # 9, June 16, 1978

Crew: Chautemps, Billy, Descamp, Goecry, Allenic, Gaullier

Airfield: Bretigny (for both departure and arrival)

Time of departure: 2:10 PM

Time of arrival: 4:25 PM

Ground temperature 12.5°

Ground pressure: 998 (at both departure and arrival)

Weather: overcast sky with downpours

Duration of flight: 2 hours 15 minutes

Time spent in stormy conditions: 10 minutes

Times lightning struck during flight: 2

Conditions and place of test:

Time (GMT): 1:32 PM and 1:20 PM

Region flown over: 50 nautical miles west of Rennes

Conditions of flight:

Speed: 220 knots

Altitude: 100 FL

Temperature: -4°C

Type of clouds: isolated cumulonimbus

Precipitation: light ~~hate~~ hail

Amount of turbulence: low to moderate

Weather conditions when lightning struck:

1st bolt that struck: this took place upon entering isolated cumulonimbus rather poorly defined by the radar. There was no turbulence or precipitation. 2nd lightning bolt: 1 to 2 nautical miles from the edge of the cumulonimbus with neither precipitation nor turbulence.

Phenomena observed before lightning struck:

None. This surprised the crew. The pilot had not yet decided to start up the recorders.

What happened when lightning struck:

Lightning seemed to hit the measuring rod.
without noise.

Rather bright flash

plate 13

Lightning-caused damage observed in flight:

Loss of wing defroster a few seconds after the first lightning bolt struck. On the ground, we also noticed the loss of a flight ignition circuit.

Findings:

Less conclusive than before [nearly illegible]. We were struck at the edge of the cumulonimbus.

In-Flight Lightning Test

Flight # 10, June 30, 1978

Crew: Chautemps, Descamp, Rennesson, Coquemar, Gaullier, Allenic

Airfield: Bretigny (for both departure and arrival)

Time of Departure: 3:25 PM Time of arrival: 7:35 PM

Ground temperature: 20°

Ground pressure: 1009 (for both departure and arrival)

Wind and weather: 280/10, overcast skies

Duration of flight: 4 hours 10 minutes

Time spent in stormy conditions: 1 hour

Times lightning struck during flight: 4

Conditions and place of test:

Time (GMT): 5:00 PM

Altitude: FL 140

Region flown over: 40 nautical miles south of Montpellier

Conditions of flight:

Speed: 190 knots Altitude: FL 140 Temperature 0°C

Type of clouds: unformed [illegible] with a few cumulonimbus inside
this mass

Precipitation: light ~~hale~~ hail

Amount of turbulence: low

Weather conditions when lightning struck:

A few cumulonimbus of small diameter 1 to 2 nautical miles in
an unformed cloudy mass seen by ground radar as large cumulonimbus.

Phenomena observed before lightning struck:

Slight precipitation and radio noise.

What happened when lightning struck:

Four flashes hit the front rod. Light thud at copilot's feet during
each discharge. A fifth flash was seen near the airplane. This
phenomenon resembled ball lightning.

plate 14.

Lightning-caused damage observed in flight:

None

Findings:

The lightning struck when the airplane was entering cumulonimbus clouds. The flashes were rather intense, but never made a large noise (explosive type).

In-Flight Lightning Test

Flight # 11, July 4, 1978

Crew: Chautemps, Versinger, Descamps, Bouilliez, Gaullier, Allenic,
Vicens

Airfield: Bretigny (for both takeoff and landing)

Departure time: 2:34 PM

Arrival time: 4:18

Ground temperature: 13°C

Ground pressure: 997 (for both takeoff and landing)

Wind and weather: 240/16 -- a few cumulonimbus

Duration of flight: 1 hour 55 minutes

Time spent in stormy conditions: 1 hour 10 minutes

Times lightning struck during flight: 7 flashes & 1 brush discharge
on the rod

Conditions and place of test:

Time (GMT): 1:00 PM

Altitude: FL 100

Region flown over: Between Chartres and Etampes

Conditions of flight:

Speed: 190 Altitude: FL 100 Temperature: 5°C

Type of clouds: Small cumulonimbus

Precipitation: ~~Hale~~ Hail

Amount of turbulence: Medium to strong

Weather conditions when lightning struck:

Small-diameter cumulonimbus clouds whose summits did not exceed
12-15 thousand ft, with lightning, hale, and frost formation.

Phenomena observed before lightning struck:

Radio noise

What happened when lightning struck:

Flashes observed on the measuring rod and on the right side of the
airplane. The noise heard was slightly greater than at other times

plate 15

when lightning struck. The lightning strikes occurred when the airplane was entering cumulonimbus clouds.

Lightning-caused damage observed in flight:

None

Findings:

Out of the 7 lightning flashes, there were probably one or two that didn't touch the measuring rod since we observed impacts on the right side of the fuselage, starting at the radar (in the center) and running along the fuselage. A brush discharge also hit the front rod. We passed through a cumulonimbus with cloud-to-ground lightning.

In-Flight Lightning Test

Flight # 12, July 11, 1978

Crew: Tranoski, Bertrand, Hebert, Haguet, Allenic, Gaullier

Airfield: Bretigny (for both takeoff and landing)

Departure time: 4:20 PM

Arrival time: 6:00 PM

Ground pressure: 1002 (for both takeoff and landing)

Wind and weather: 22/12 -- stratus clouds

Duration of flight: 1 hour 50 minutes

Time spent in stormy conditions: 15 minutes

Times lightning struck during flight: once

Conditions and place of test:

Time (GMT): 1:00 PM

Altitude: 150 (FL)

Region flown over: south Moulin

Conditions of flight:

Speed: 170 Altitude: 150 and 120 (FL) Temperature: -3°C

Type of clouds: Cumulonimbus in the midst of a large cumulus

Precipitation: Light ~~hate~~ hail

Amount of turbulence: average

Weather conditions when lightning struck:

A small cumulonimbus in the midst of a cloud mass having the form of a cumulus.

Phenomena observed before lightning struck:

None

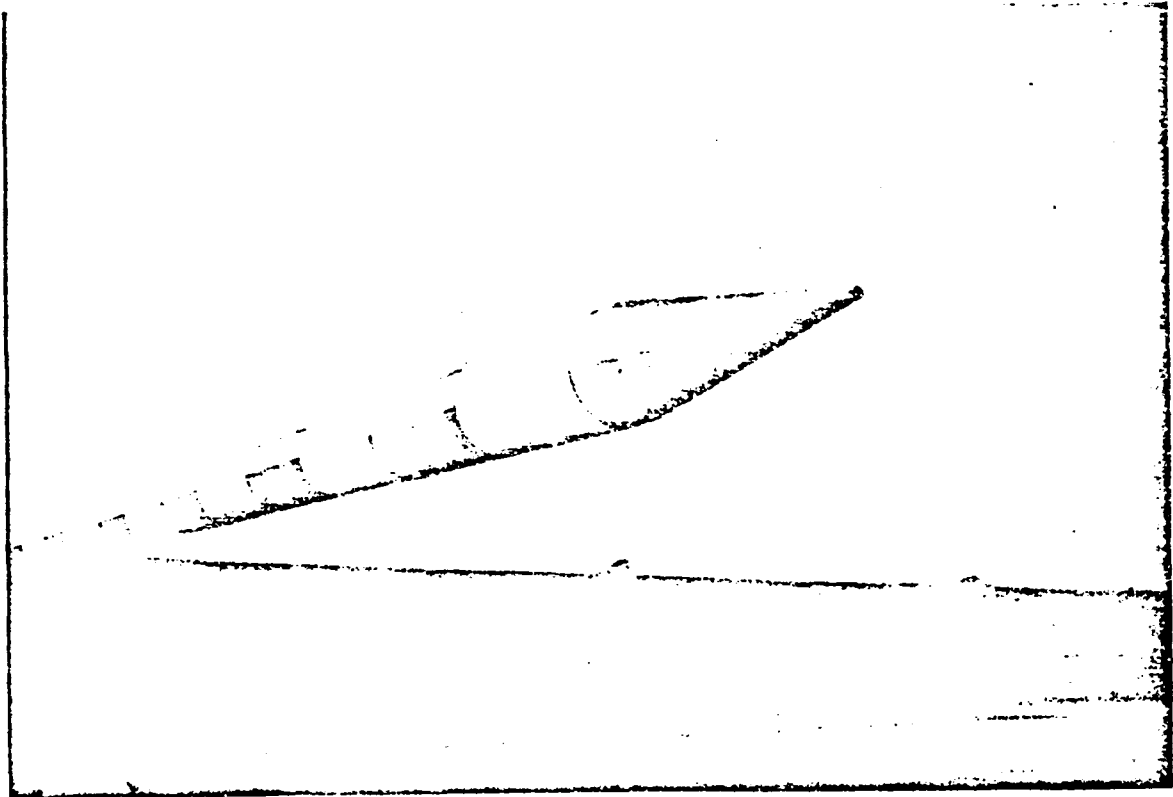
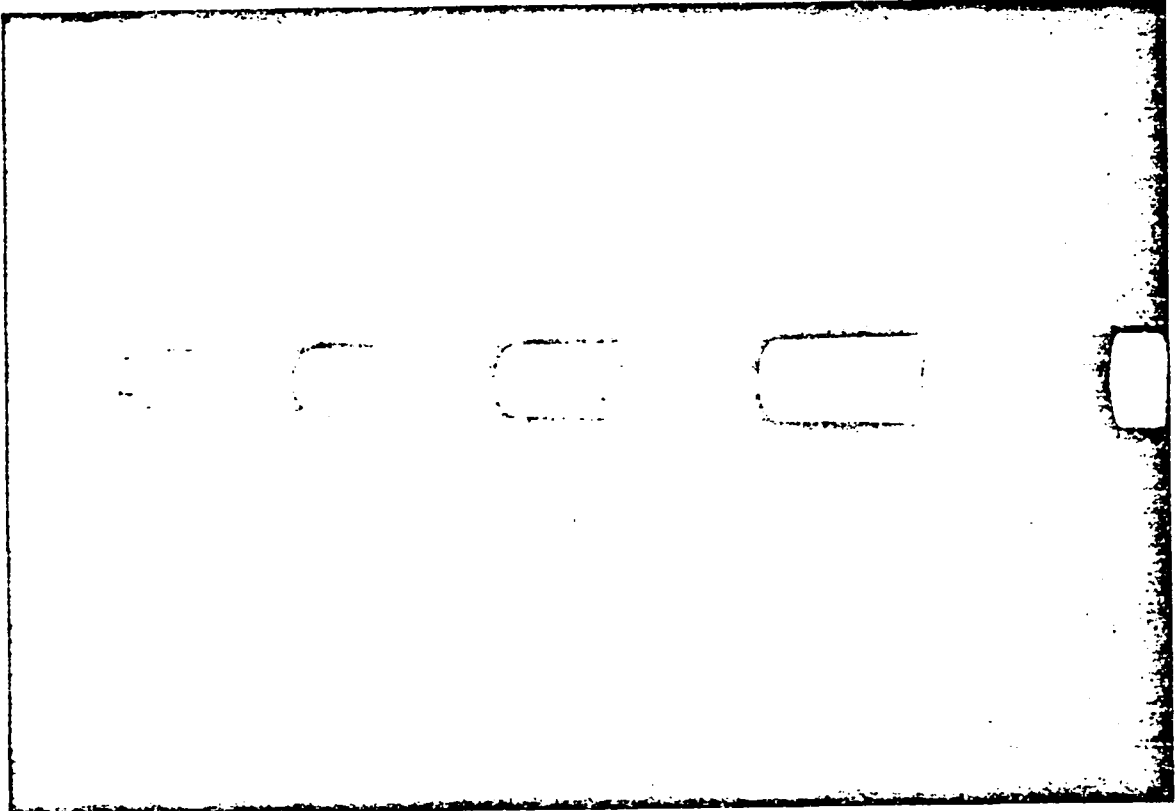
What happened when lightning struck:

A flash. The crew did not hear any noise, but an observer without earphones [? -- nearly illegible] heard a fairly loud click. The lightning struck while the airplane was intercepting the cumulonimbus tangentially.

Findings:

The lightning discharge seemed rather weak since there were only small impacts on the measuring rod.

- 40 -



Front and Rear Rod

Plate 17

| FLIGHT | TIME | ROD | I_{max} in KA | TIME FROM 0 to I_{max} in μs | $\frac{dI}{dt}_{max}$ in kA/ μs | $\int I dt$ in C | TOTAL DURATION in ms |
|--------|-------------|-------|--------------------|---|---|---------------------|-------------------------------|
| 1 | 14h53' 11" | FRONT | 15 | 2.5 | 2 | 7 | 5 |
| 1 | 15h20' 27" | FRONT | 2.5 | 10 | 0.1 | 1 | 4 |
| 5 | 15h42' 20" | FRONT | 28 | 70 | 0.5 | 2.5 | 0.25 |
| 5 | " | REAR | 8 | 70 | 0.16 | 0.7 | 0.25 |
| 5 | 15h43' 16" | FRONT | 45 | 10 | 6 | 2.5 | 4 |
| 5 | " | REAR | 16 | 10 | 2.1 | 0.8 | 4 |
| 9 | 15h35' 40" | FRONT | 14 | 15 | 1 | 2 | 5 |
| 9 | " | REAR | 6 | 15 | 0.2 | 0.8 | 3 |
| 9 | 15h40' 16" | FRONT | 4 | 30 | 0.1 | 10 | 9 |
| 10 | 17h46' 39" | FRONT | 3.5 | 10 | 0.3 | 9 | 8 |
| 10 | 17h52' 11" | FRONT | 50 | 50 | 4 | 10 | 6 |
| 10 | " | REAR | 50 | 50 | 4 | 10 | 6 |
| 11 | 15h04' 00" | FRONT | 4 | 20 | 0.06 | 8 | 16 |
| 11 | 15h12' 21" | FRONT | 8 | 50 | 0.07 | 1.5 | 2.5 |
| 11 | 15h 33' 24" | FRONT | 3 | 15 | 0.1 | 4 | 9 |
| 11 | 15h43' 30" | FRONT | 70 | 20 | 2.6 | 3 | 4 |
| 11 | " | REAR | 160 | 20 | 6 | 6 | 4 |
| 11 | 15h46' 02" | FRONT | 6 | 10 | 0.3 | 10 | 18 |

CHARACTERISTICS OF LIGHTNING AT HIGH ALTITUDES

1978 SERIES OF TESTS

Plate 18

CEAT - REPRODUCTION F 739 AC

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 1

Time Lightning Struck: 14:53:11

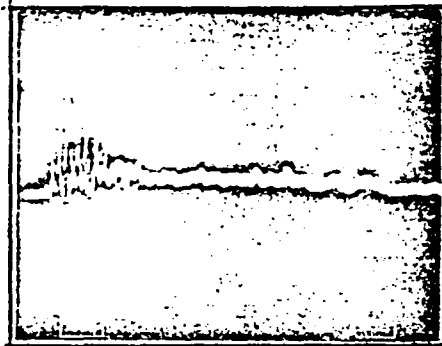
Rod: Front

Attenuators: 20dB+6dB=26dB

Horiz. Scale: 0.5ms/c

Vert. Scale: 200mV/c

or 4 kA/c



A

Horiz. Scale: 100μs/c

Vert. Scale: 200mV/c

or 4 kA/c



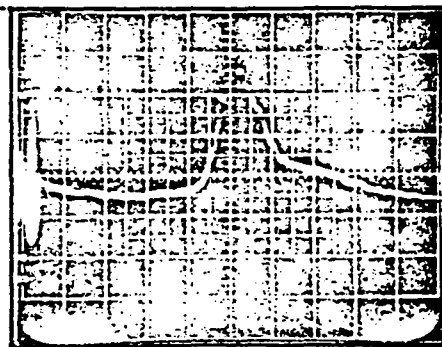
B

Detail A

Horiz. Scale: 5μs/c

Vert. Scale: 200mV/c

or 4 kA/c



Detail B

Remarks:

6 dB attenuation due to copying process

Plate 19

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 1

Time Lightning Struck: 15:20:27

Rod: Front

Attenuators: 20dB+6dB=26dB

Horiz. Scale: $500 \mu s/c$

Vert. Scale: $50 mV/c$

or $1 kA/c$

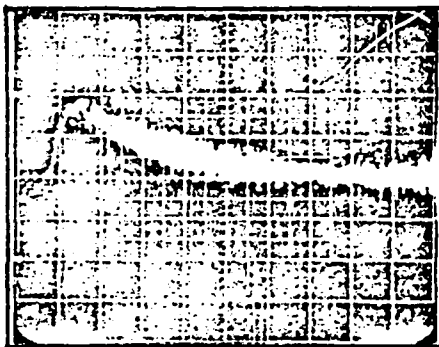


A

Horiz. Scale: $50 \mu s/c$

Vert. Scale: $50 mV/c$

or $1 kA/c$

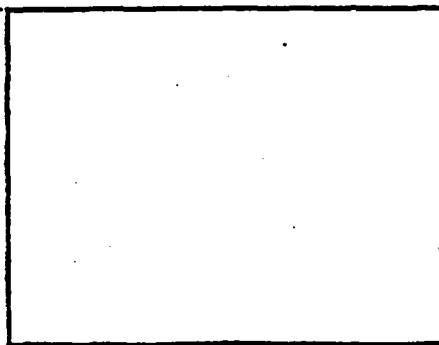


Détail A

Horiz. Scale: k

Vert. Scale: k

or kA/c



Détail

Remarks:

6 dB attenuation due to copying process

Plate 20

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:42:20

Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: $50 \mu s / c$

Vert. Scale: $200 mV / c$

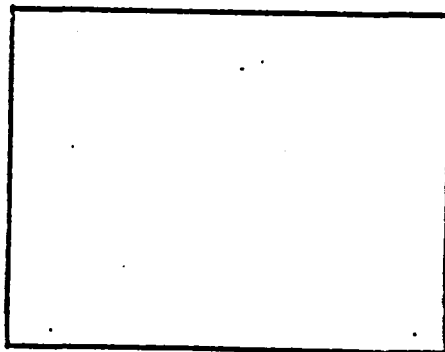
or $8 kA / c$



Horiz. Scale: $/c$

Vert. Scale: $/c$

or kA / c

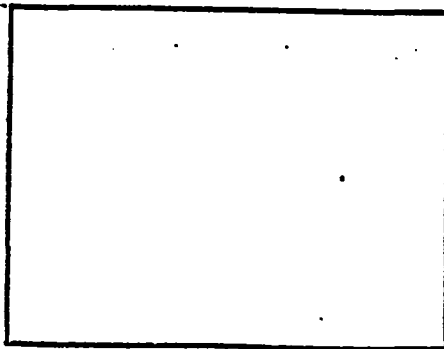


Détail

Horiz. Scale: $/c$

Vert. Scale: $/c$

or kA / c



Détail

Remarks:

Plate 21

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:42:20

Rod: Rear

Attenuators: 26dB+6dB=32dB

Horiz. Scale: $50 \mu s / c$

Vert. Scale: $100 mV / c$

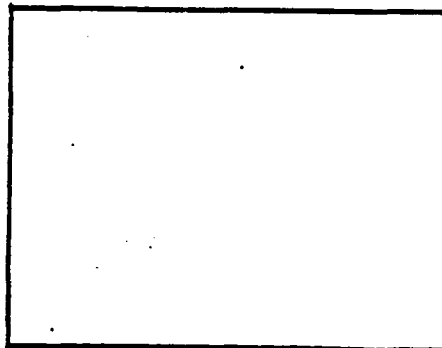
or $4 kA / c$



Horiz. Scale: $/c$

Vert. Scale: $/c$

or kA / c

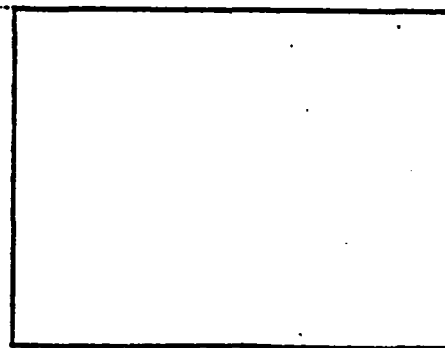


Détail

Horiz. Scale: $/c$

Vert. Scale: $/c$

or kA / c



Détail

Remarks:

Plate 22

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:43:16

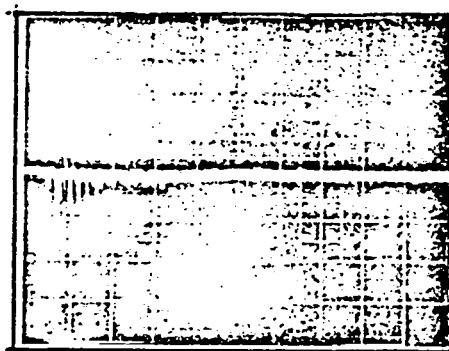
Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: *1ms/c*

Vert. Scale: *500mV/c*

or *20 kA/c*

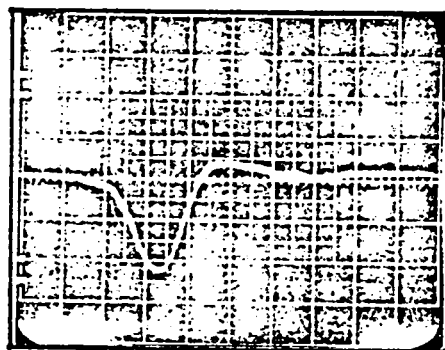


A

Horiz. Scale: *10μs/c*

Vert. Scale: *500mV/c*

or *20 kA/c*

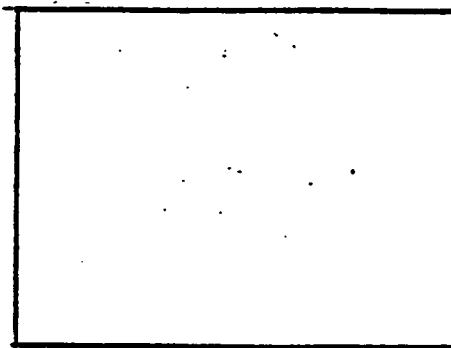


Détail A

Horiz. Scale: *μs*

Vert. Scale: *μV*

or *kA/c*



Détail

Remarks:

Plate 23

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:43:16

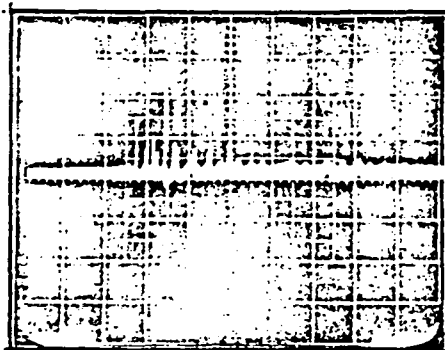
Rod: Rear

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 0.5ms/c

Vert. Scale: 200mV/c

or 8 kA/c

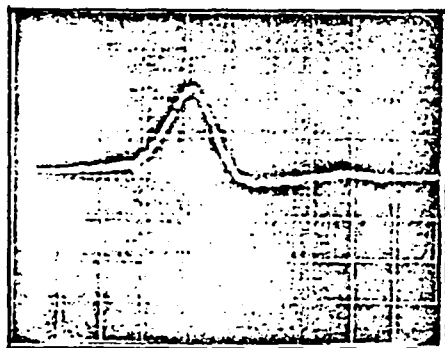


A

Horiz. Scale: 10μs/c

Vert. Scale: 200mV/c

or 8 kA/c

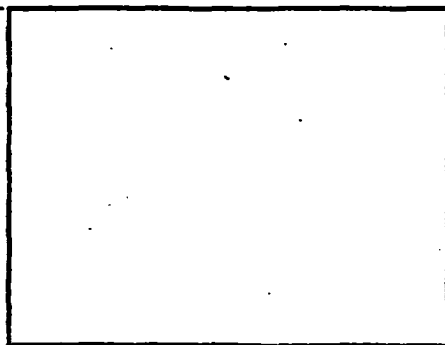


Détail A

Horiz. Scale: /c

Vert. Scale: /c

or kA/c



Détail

Remarks:

Plate 24

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 9

Time Lightning Struck: 15:35:40

Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: $1\text{ ms}/\text{c}$

Vert. Scale: $100\text{ mV}/\text{c}$

or $4\text{ kA}/\text{c}$

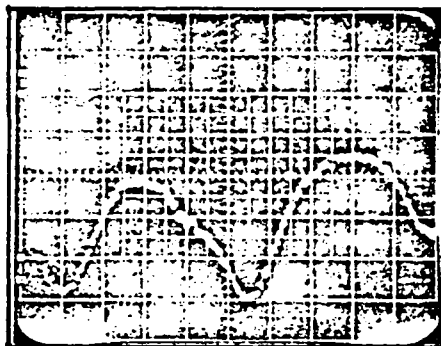


A

Horiz. Scale: $10\text{ }\mu\text{s}/\text{c}$

Vert. Scale: $100\text{ mV}/\text{c}$

or $4\text{ kA}/\text{c}$

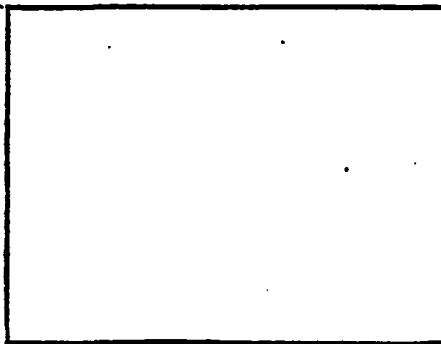


Détail A

Horiz. Scale: c

Vert. Scale: c

or kA/c



Détail

Remarks:

Plate 25

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 9

Time Lightning Struck: 15:35:40

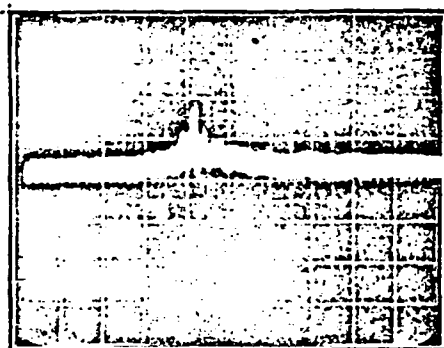
Rod: Rear

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 0.5ms/c

Vert. Scale: 100mV/c

or 4 kA/c



A

Horiz. Scale: 10μs/c

Vert. Scale: 100mV/c

or 4 kA/c

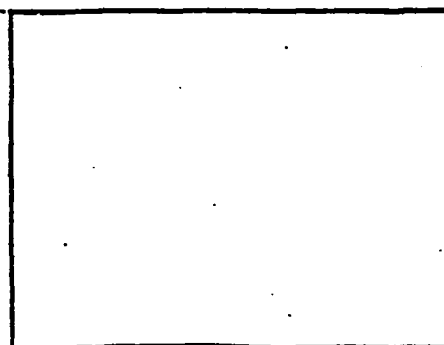


Détail A

Horiz. Scale: /c

Vert. Scale: /c

or kA/c



Détail

Remarks:

Plate 26

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 9

Time Lightning Struck: 15:40:16

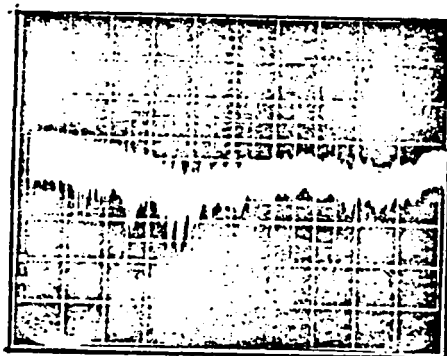
Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 1ms/c

Vert. Scale: 50mV/c

or 2 kA/c

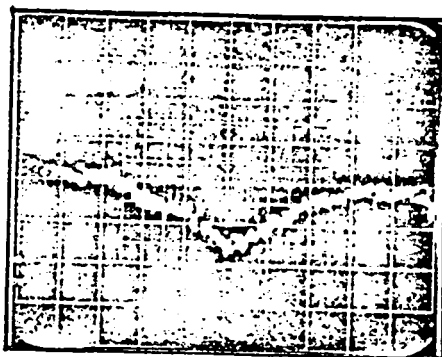


A

Horiz. Scale: 10μs/c

Vert. Scale: 50mV/c

or 2 kA/c

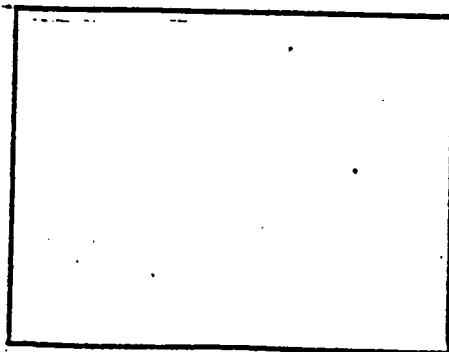


Détail A

Horiz. Scale: k

Vert. Scale: k

or kA/c



Détail

Remarks:

Plate 27

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 10

Time Lightning Struck: 17:46:39

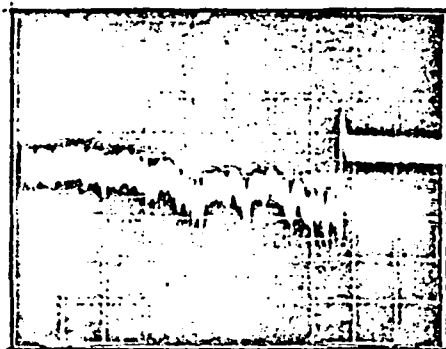
Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 1ms/c

Vert. Scale: 50mV/c

or 2 kA/c



A B

Horiz. Scale: 100μs/c

Vert. Scale: 50mV/c

or 2 kA/c



Détail A

Horiz. Scale: 50μs/c

Vert. Scale: 50mV/c

or 2 kA/c



Détail B

Remarks:

Plate 28

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 10

Time Lightning Struck: 17:52:11

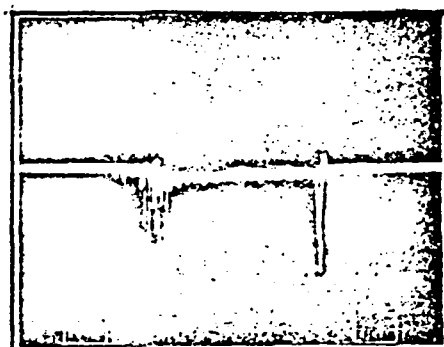
Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 1ms/c

Vert. Scale: 500mV/c

or 20 kA/c



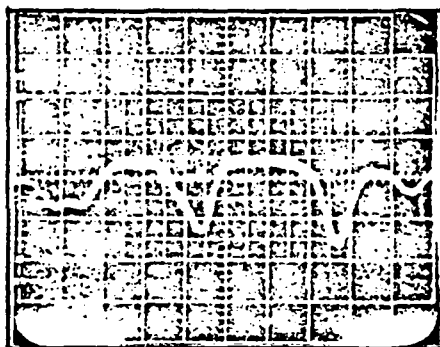
A

B

Horiz. Scale: 20μs/c

Vert. Scale: 500mV/c

or 20 kA/c

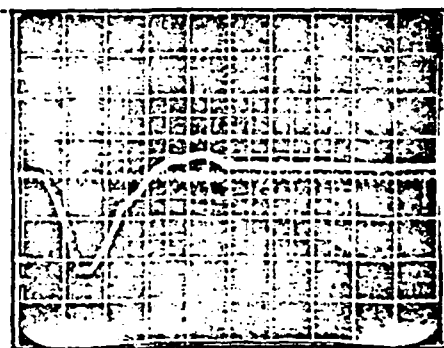


Détail A

Horiz. Scale: 50μs/c

Vert. Scale: 500mV/c

or 20 kA/c



Détail B

Remarks:

Plate 29

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 11

Time Lightning Struck: 15:04:00

Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 2ms /c

Vert. Scale: 50mV/c

or 2 kA/c

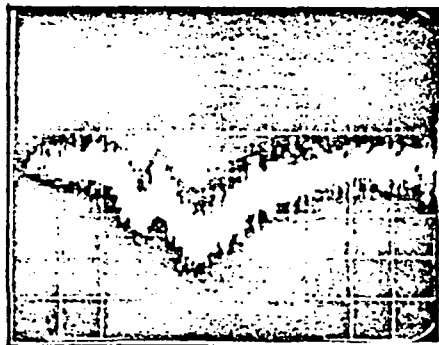


A

Horiz. Scale: 50μs /c

Vert. Scale: 50mV/c

or 2 kA/c

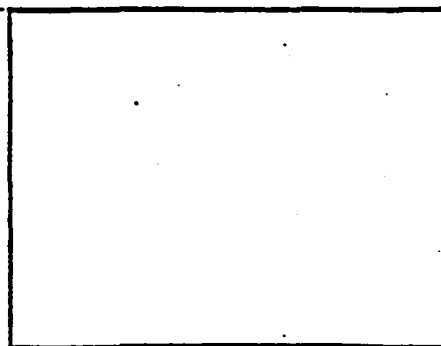


Détail A

Horiz. Scale: /c

Vert. Scale: /c

or kA/c



Détail

Remarks:

Plate 30

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 11

Time Lightning Struck: 15:12:21

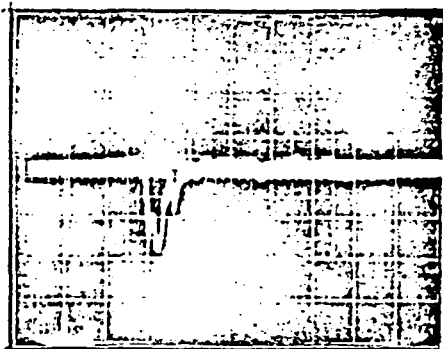
Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 0,5ms/c

Vert. Scale: 100mV/c

or 4 kA/c

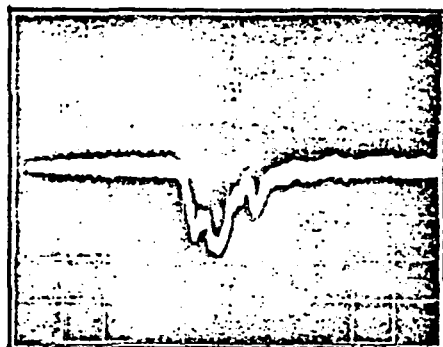


A

Horiz. Scale: 0,2ms/c

Vert. Scale: 100mV/c

or 4 kA/c

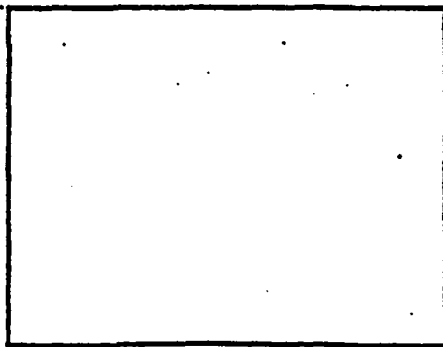


Détail A

Horiz. Scale: k

Vert. Scale: k

or kA/c.



Détail

Remarks:

Plate 31

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 11

Time Lightning Struck: 15:33:24

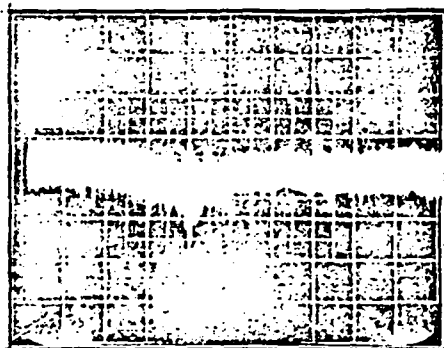
Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 1ms /c

Vert. Scale: 50mV/c

or 2 kA/c



A

Horiz. Scale: 20μs /c

Vert. Scale: 50mV/c

or 2 kA/c

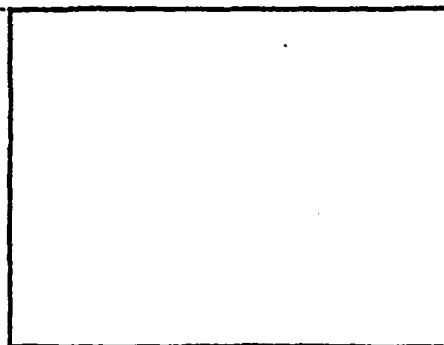


Détail A

Horiz. Scale: /c

Vert. Scale: /c

or kA/c



Détail

Remarks:

Plate 32

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 11

Time Lightning Struck: 15:43:30

Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 0,5ms/c

Vert. Scale: 0,5V/c

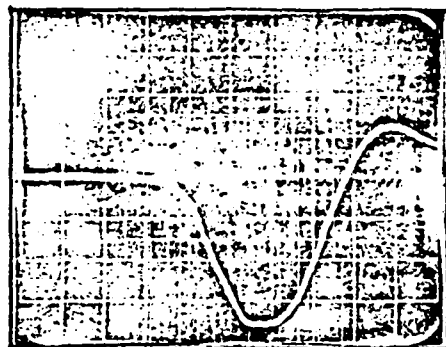
or 20 kA/c



Horiz. Scale: 20μs/c

Vert. Scale: 0,5V/c

or 20 kA/c

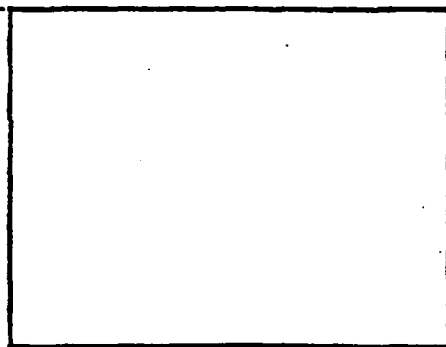


Détail A

Horiz. Scale: /c

Vert. Scale: /c

or kA/c.



Détail

Remarks:

Plate 33

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 11

Time Lightning Struck: 15:46:02

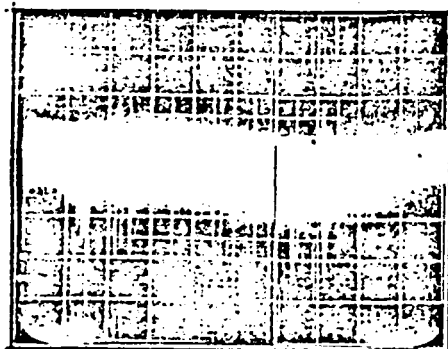
Rod: Front

Attenuators: 26dB+6dB=32dB

Horiz. Scale: 2 ms /c

Vert. Scale: 50 mV/c

or 2 kA/c



A

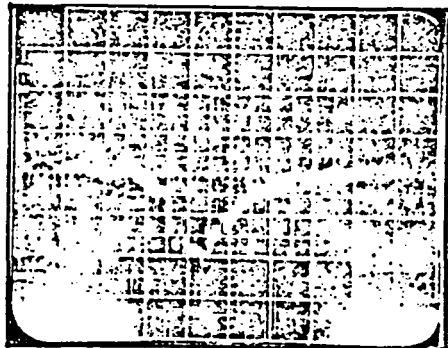
following frame

B

Horiz. Scale: 20 μ s /c

Vert. Scale: 50 mV/c

or 2 kA/c

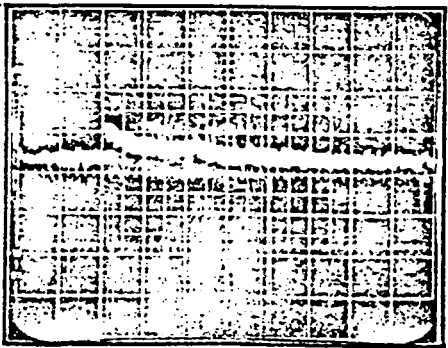


Détail A

Horiz. Scale: 20 μ s /c

Vert. Scale: 50 mV/c

or 2 kA/c



Détail B

following frame

Remarks:

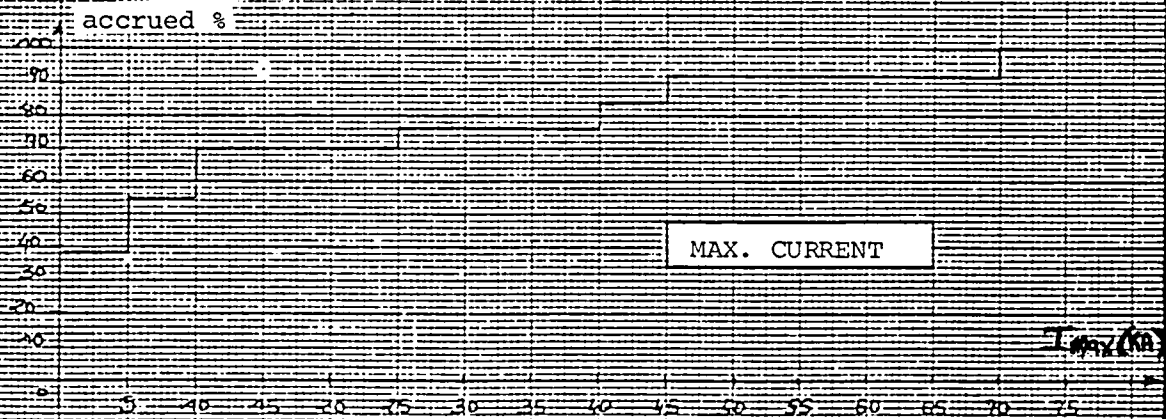
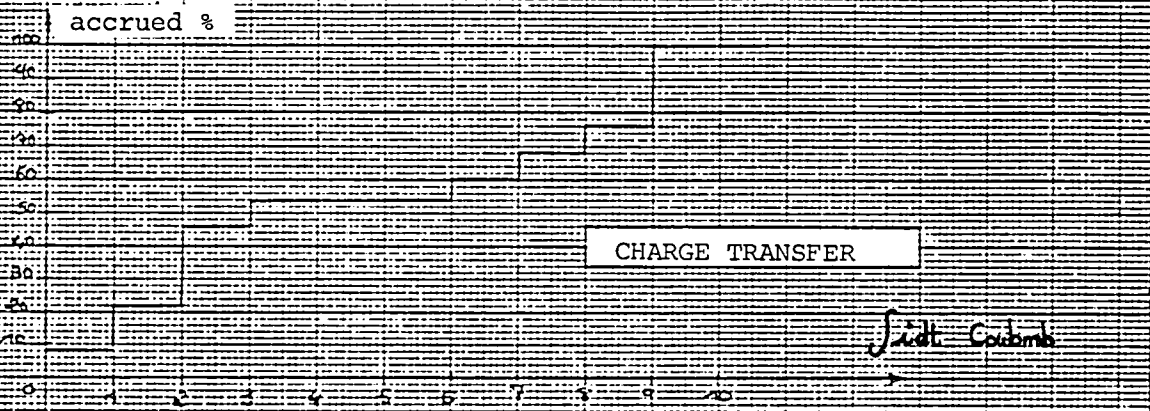
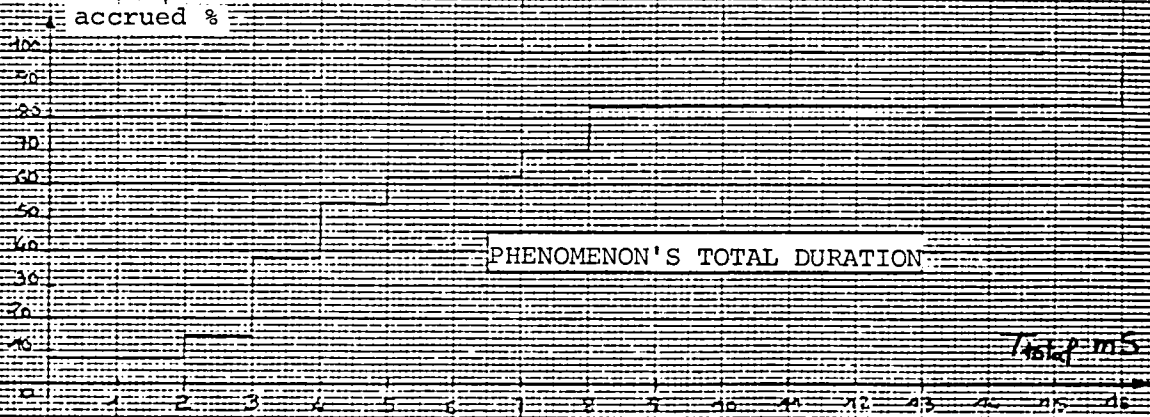
Long phenomenon

Plate 34

CENTRE D'ESSAIS AERONAUTIQUE DE TOULOUSE

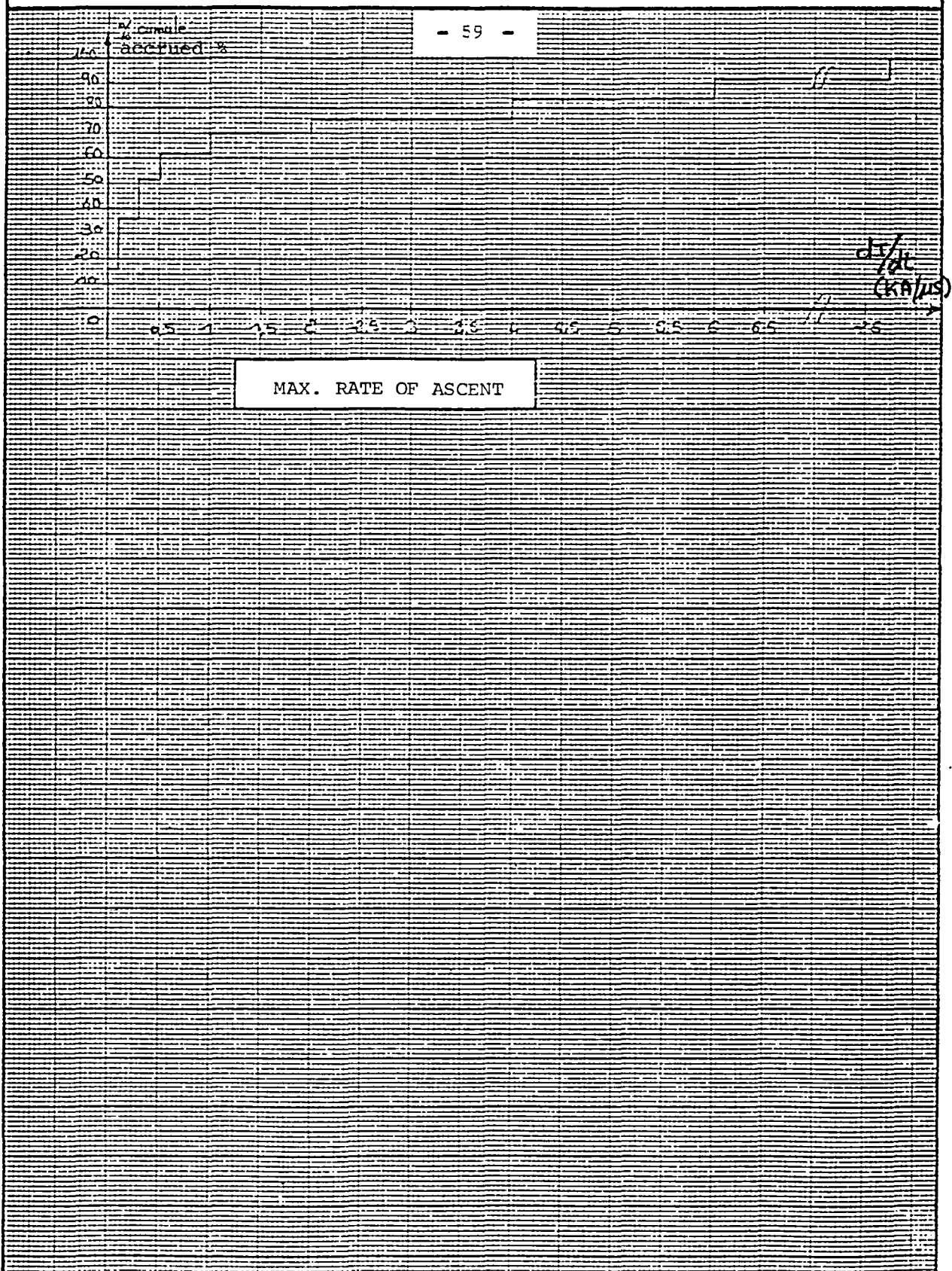
PROCES-VERBAL DE L'ESSAI N° 75/65000 P.4 et Final

- 58 -



CENTRE D'ESSAIS AERONAUTIQUE DE TOULOUSE

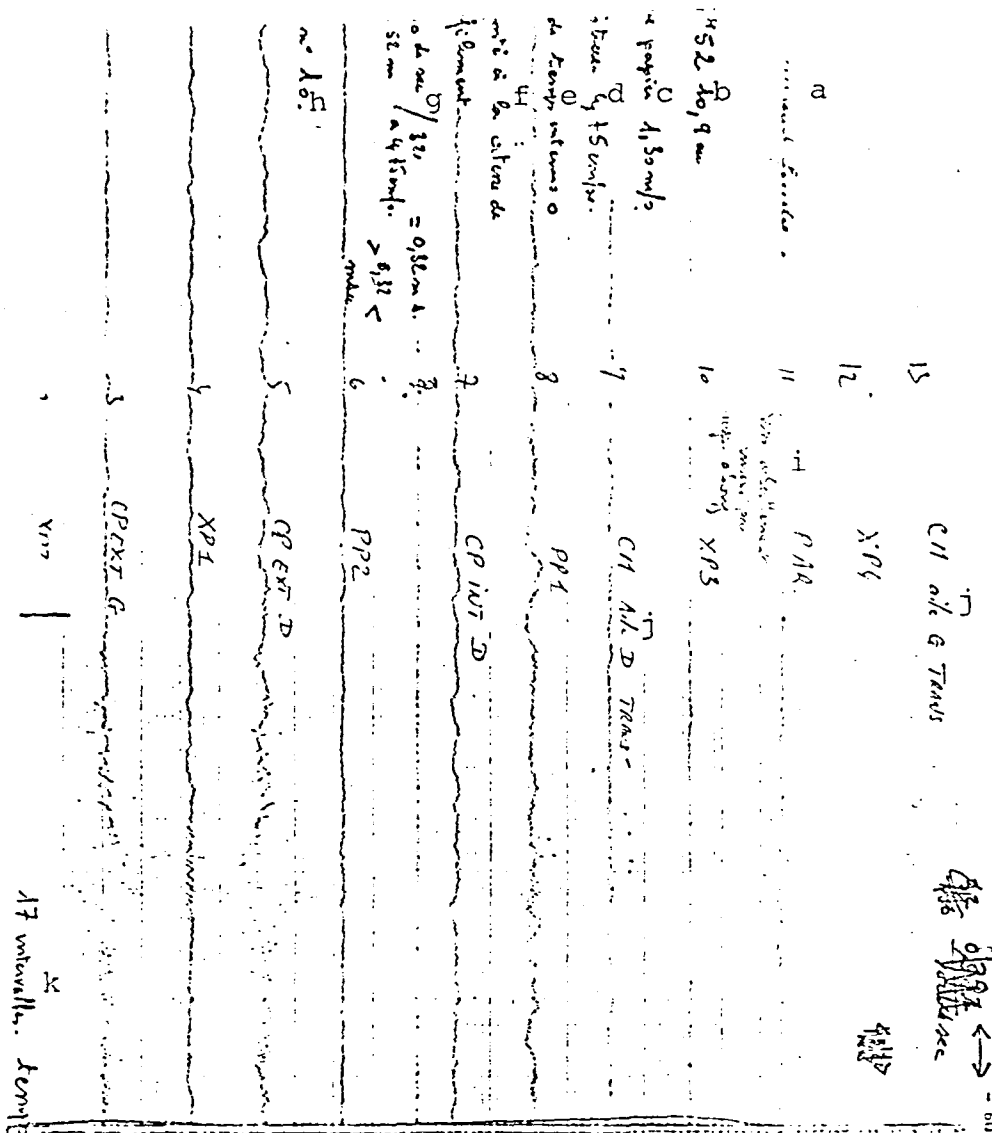
PROCES-VERBAL DE L'ESSAI N° 76/65000 P.4 et Final



CEAT Reproduction F734 AC

Lightning Bolt Current Statistics

Plate 36



- Key:
- a) lightning bolt current
 - b) 17:52:10.9
 - c) paper speed 1.30 m/sec
 - d) recorder speed [?] +5 cm/sec [?]
 - e) intern. [?] time base = 0
 - f) transferred to the processing [?] speed
 - g) [illegible]
 - h) Flight no. 10
 - i) Direction of beats reversed by Sony recorder
 - j) wing
 - k) 17 time intervals
 - G = left
 - D = right

[Translator's Note:
The captions on this
graph are nearly
illegible.]

Plate 37

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 1

Time Lightning Struck: 14:53:11

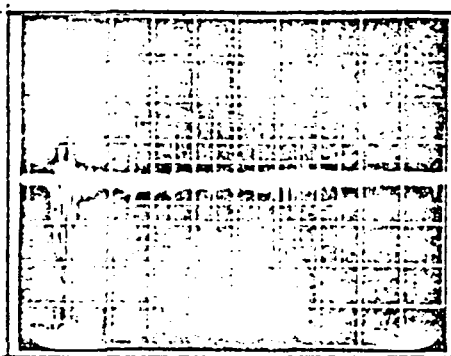
TEST LINE

Attenuators: 20 dB

Horiz. Scale: $1 \text{ mA}/\text{c}$

Vert. Scale: $0.2 \text{ V}/\text{c}$

or kA/c

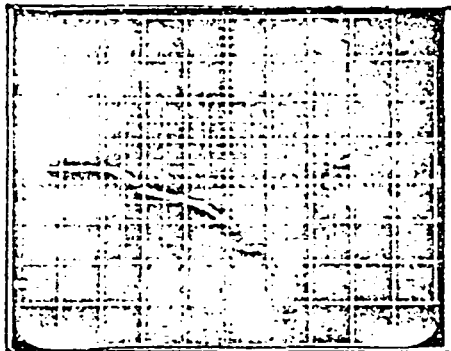


A

Horiz. Scale: $10 \mu\text{s}/\text{c}$

Vert. Scale: $0.2 \text{ V}/\text{c}$

or kA/c

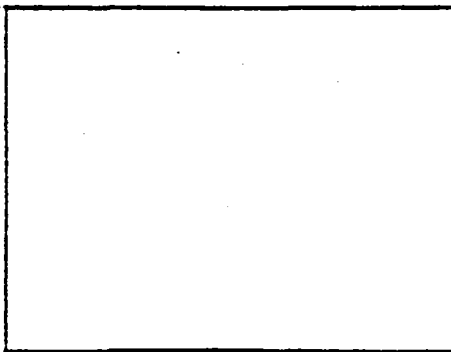


Détail A

Horiz. Scale: c

Vert. Scale: c

or kA/c



Détail

Remarks:

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 1

Time Lightning Struck: 15:20:27

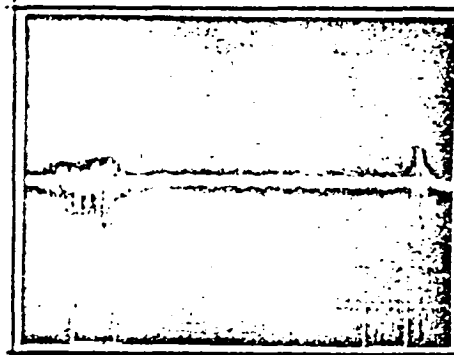
TEST LINE

Attenuators: 20 dB

Horiz. Scale: $1 \mu s / c$

Vert. Scale: $0.2 V / c$

or kA / c



A

B

Horiz. Scale: $5 \mu s / c$

Vert. Scale: $0.2 / c$

or kA / c



Détail A

Horiz. Scale: $20 \mu s / c$

Vert. Scale: $0.2 V / c$

or kA / c



Détail B

Remarks:

Plate 39

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 1

Time Lightning Struck: 15:53:17

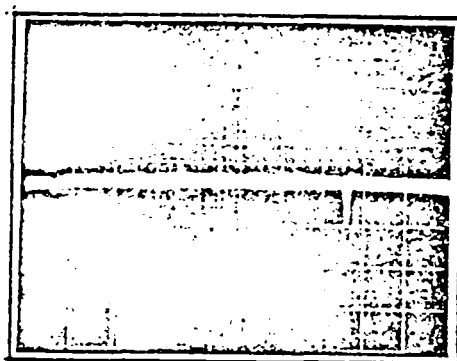
TEST LINE

Attenuators: 20 dB

Horiz. Scale: 1 mA/c

Vert. Scale: 0.2/c

or kA/c



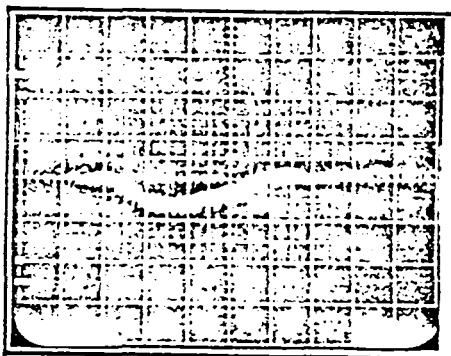
A

B

Horiz. Scale: 50 ps/c

Vert. Scale: 50 mV/c

or kA/c

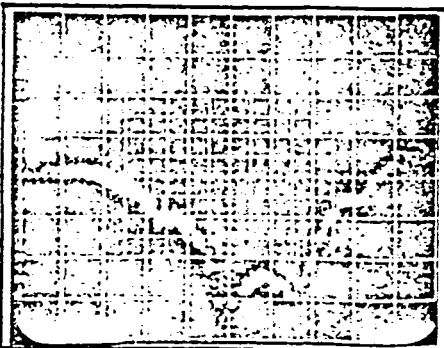


Détail A

Horiz. Scale: 20 ps/c

Vert. Scale: 50 mV/c

or kA/c



Détail B

Remarks:

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:42:20

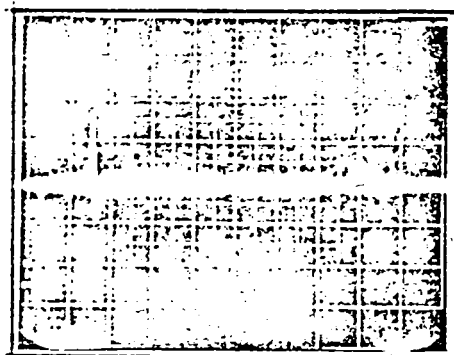
TEST LINE

Attenuators: 26 dB

Horiz. Scale: 1ms/c

Vert. Scale: 0.5V/c

or kA/c

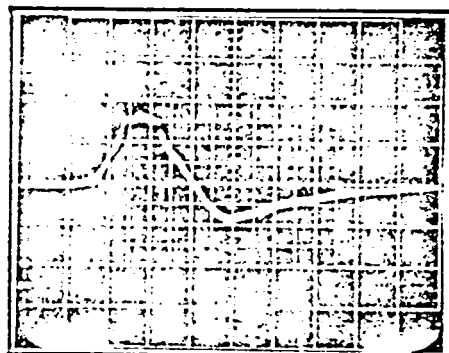


A

Horiz. Scale: 50ps/c

Vert. Scale: 0.5V/c

or kA/c



Détail A

Horiz. Scale:

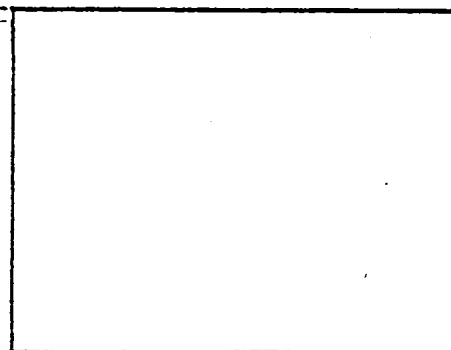
μc

Vert. Scale:

μc

or

kA/c



Détail

Remarks:

Plate 41

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:43:16

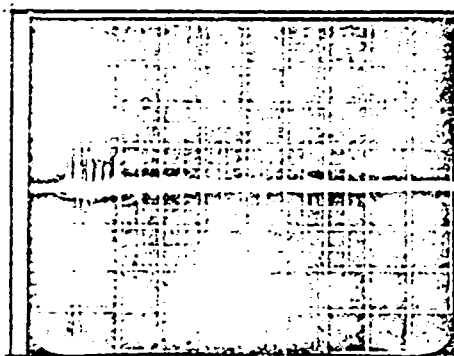
TEST LINE

Attenuators: 26 dB

Horiz. Scale: $1 \text{ ms} / \text{c}$

Vert. Scale: $1 \text{ V} / \text{c}$

or kA / c

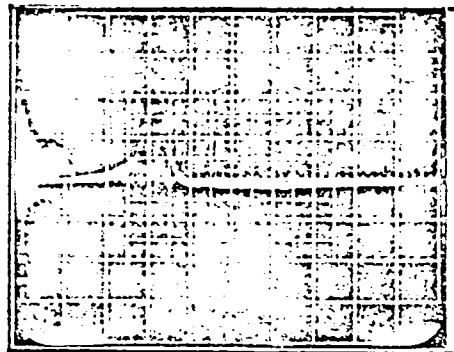


AB

Horiz. Scale: $10 \mu\text{s} / \text{c}$

Vert. Scale: $1 \text{ V} / \text{c}$

or kA / c

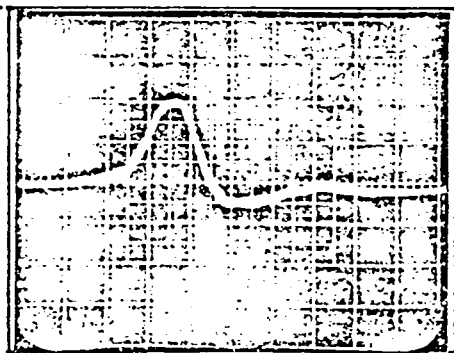


Détail A

Horiz. Scale: $10 \mu\text{s} / \text{c}$

Vert. Scale: $1 \text{ V} / \text{c}$

or kA / c



Détail B

Remarks:

Plate 42

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:47:38

TEST LINE

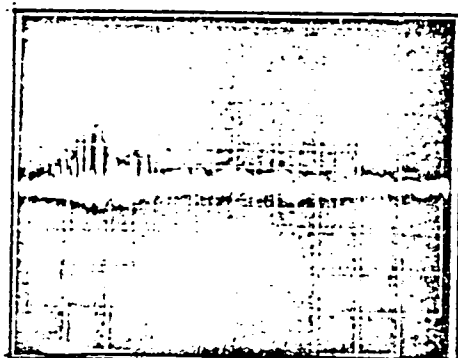
Attenuators: 26 dB

Horiz. Scale: $0.5 \mu s/c$

Vert. Scale: $0.2 V/c$

or

kA/c



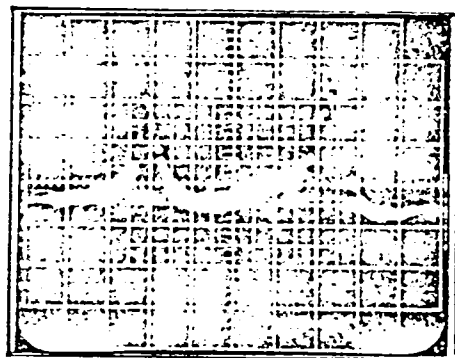
A B

Horiz. Scale: $20 \mu s/c$

Vert. Scale: $0.1 V/c$

or

kA/c



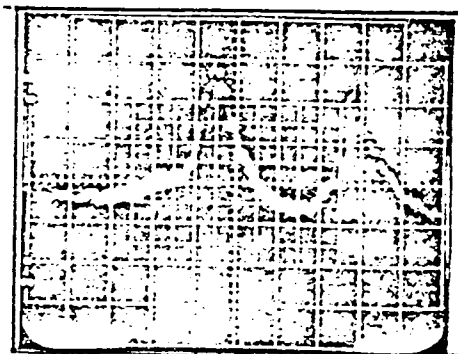
Détail A

Horiz. Scale: $10 \mu s/c$

Vert. Scale: $0.1 V/c$

or

kA/c



Détail B

Remarks:

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 5

Time Lightning Struck: 15:47:38

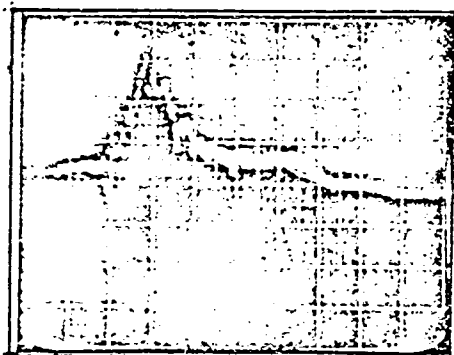
TEST LINE

Attenuators: 26 dB

Horiz. Scale: 20 μ s/c

Vert. Scale: 0.1 V/c

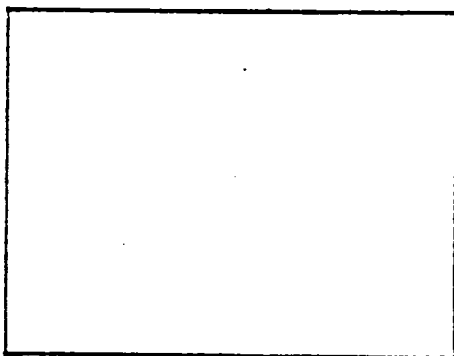
or kA/c



Horiz. Scale: /c

Vert. Scale: /c

or kA/c

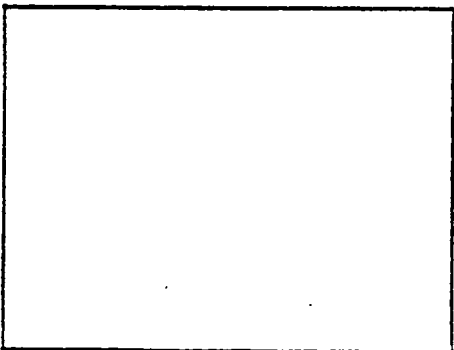


Détail

Horiz. Scale: /c

Vert. Scale: /c

or kA/c



Détail

Remarks:

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 9

Time Lightning Struck: 15:35:40

TEST LINE

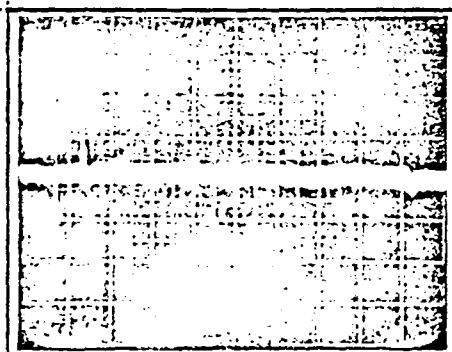
Attenuators: 26 dB

Horiz. Scale: $1 \text{ mA}/\text{c}$

Vert. Scale: $0.1 \text{ V}/\text{c}$

or

kA/c



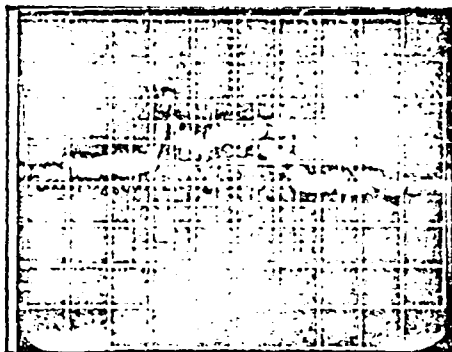
A

Horiz. Scale: $20 \text{ ps}/\text{c}$

Vert. Scale: $50 \text{ mV}/\text{c}$

or

kA/c



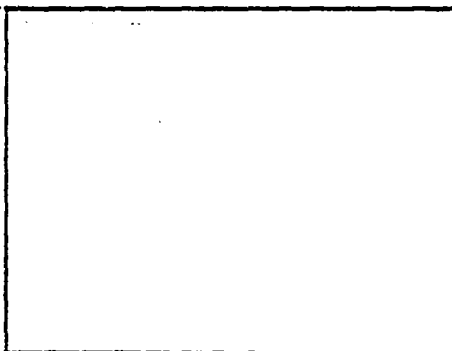
Détail A

Horiz. Scale: c

Vert. Scale: c

or

kA/c



Détail

Remarks:

Plate 45

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 9

Time Lightning Struck: 15:40:16

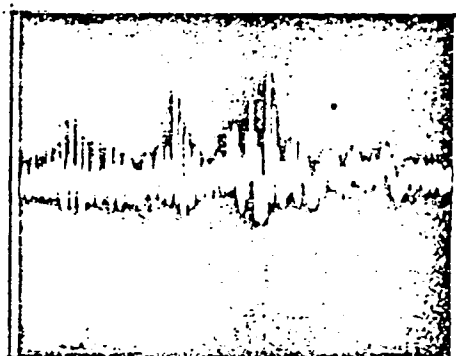
TEST LINE

Attenuators: 26 dB

Horiz. Scale: 0.5 μ s/c

Vert. Scale: 50 mV/c

or kA/c



A B C

Horiz. Scale: 10 μ s/c

Vert. Scale: 50 mV/c

or kA/c

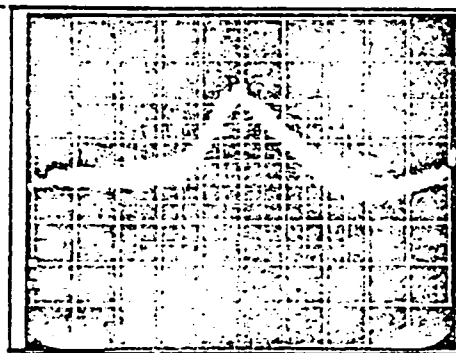


Détail A

Horiz. Scale: 10 μ s/c

Vert. Scale: 50 mV/c

or kA/c



Détail B

Remarks:

Plate 46

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 9

Time Lightning Struck: 15:40:16

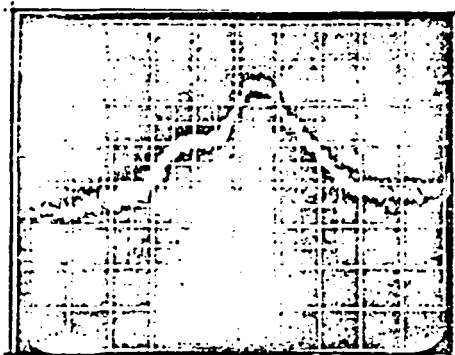
TEST LINE

Attenuators: 26 dB

Horiz. Scale: $10 \mu s/c$

Vert. Scale: $50 mV/c$

or kA/c

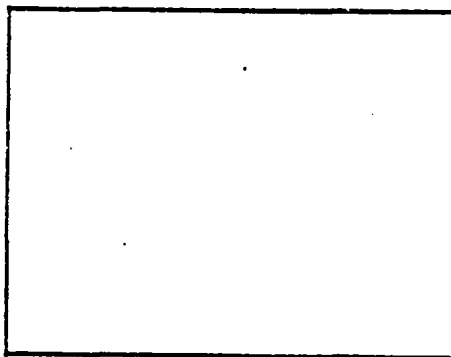


Detail C

Horiz. Scale: $/c$

Vert. Scale: $/c$

or kA/c

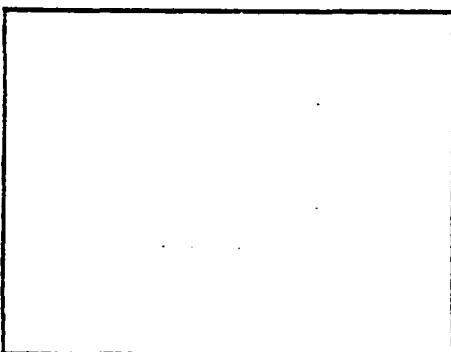


Détail

Horiz. Scale: $/c$

Vert. Scale: $/c$

or kA/c



Détail

Remarks:

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 10

Time Lightning Struck: 17:52:11

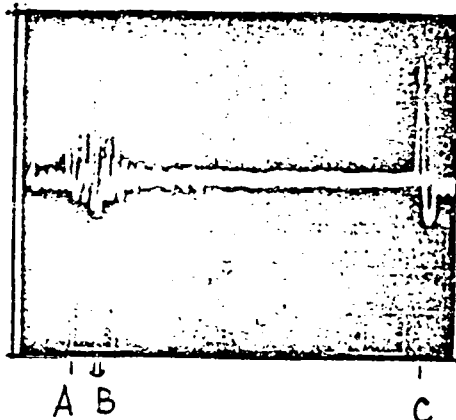
TEST LINE

Attenuators: 26 dB

Horiz. Scale: 0.5 ms/c

Vert. Scale: 0.1 V/c

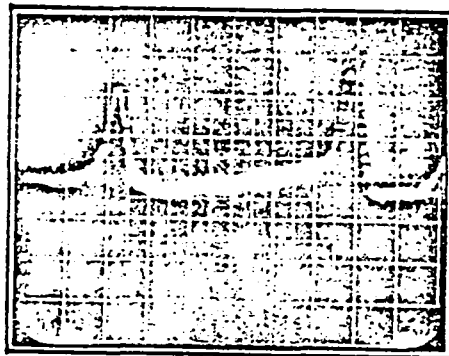
or kA/c



Horiz. Scale: 20 ps/c

Vert. Scale: 0.1 V/c

or kA/c

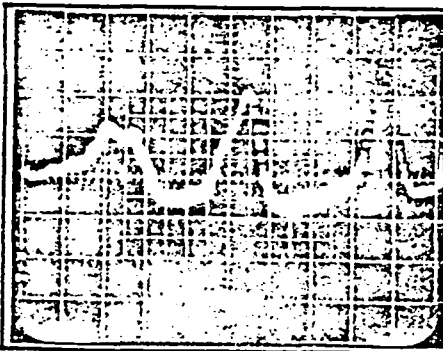


Détail A

Horiz. Scale: 20 ps/c

Vert. Scale: 0.1 V/c

or kA/c



Détail B

Remarks:

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 10

Time Lightning Struck: 17:52:11

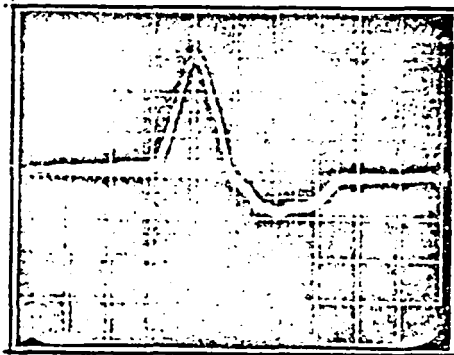
TEST LINE

Attenuators: 26 dB

Horiz. Scale: 50 μ s/c

Vert. Scale: 0.1 V/c

or kA/c

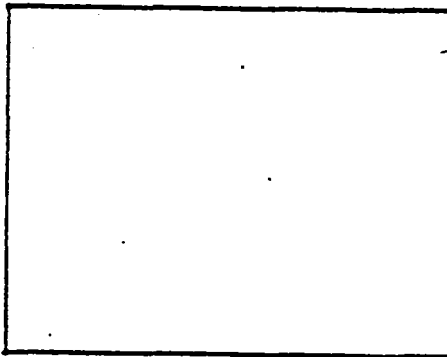


Detail C

Horiz. Scale: /c

Vert. Scale: /c

or kA/c

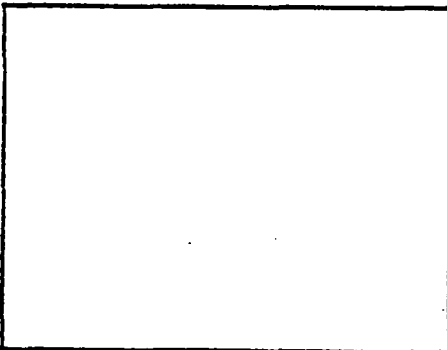


Détail

Horiz. Scale: /c

Vert. Scale: /c

or kA/c



Détail

Remarks:

LIGHTNING DISCHARGES ON TRANSALL C160A-04

Flight No. 11

Time Lightning Struck: 15:43:30

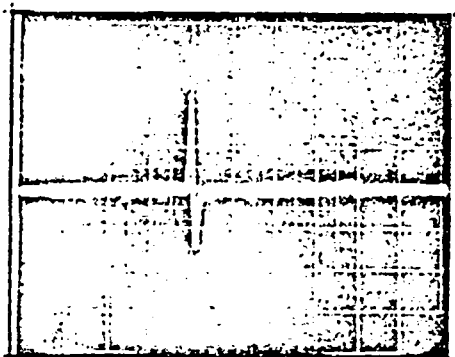
TEST LINE

Attenuators: 26 dB

Horiz. Scale: 0,5ms/c

Vert. Scale: 0,2V /c

or kA/c



A

Horiz. Scale: 20ps /c

Vert. Scale: 0,2V /c

or kA/c

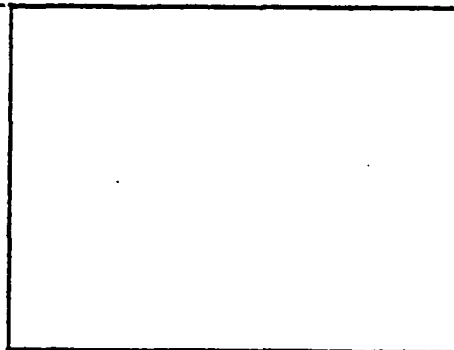


Détail A

Horiz. Scale: /c

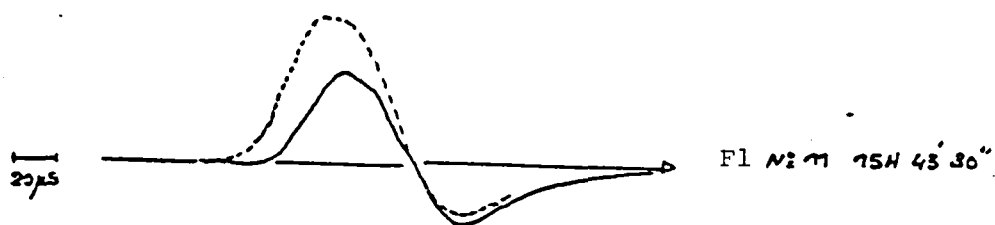
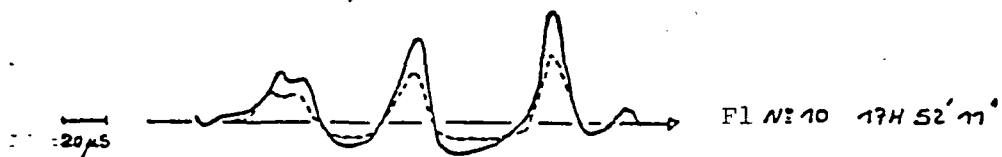
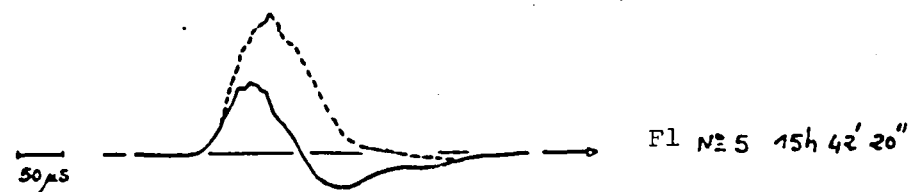
Vert. Scale: /c

or kA/c



Détail B

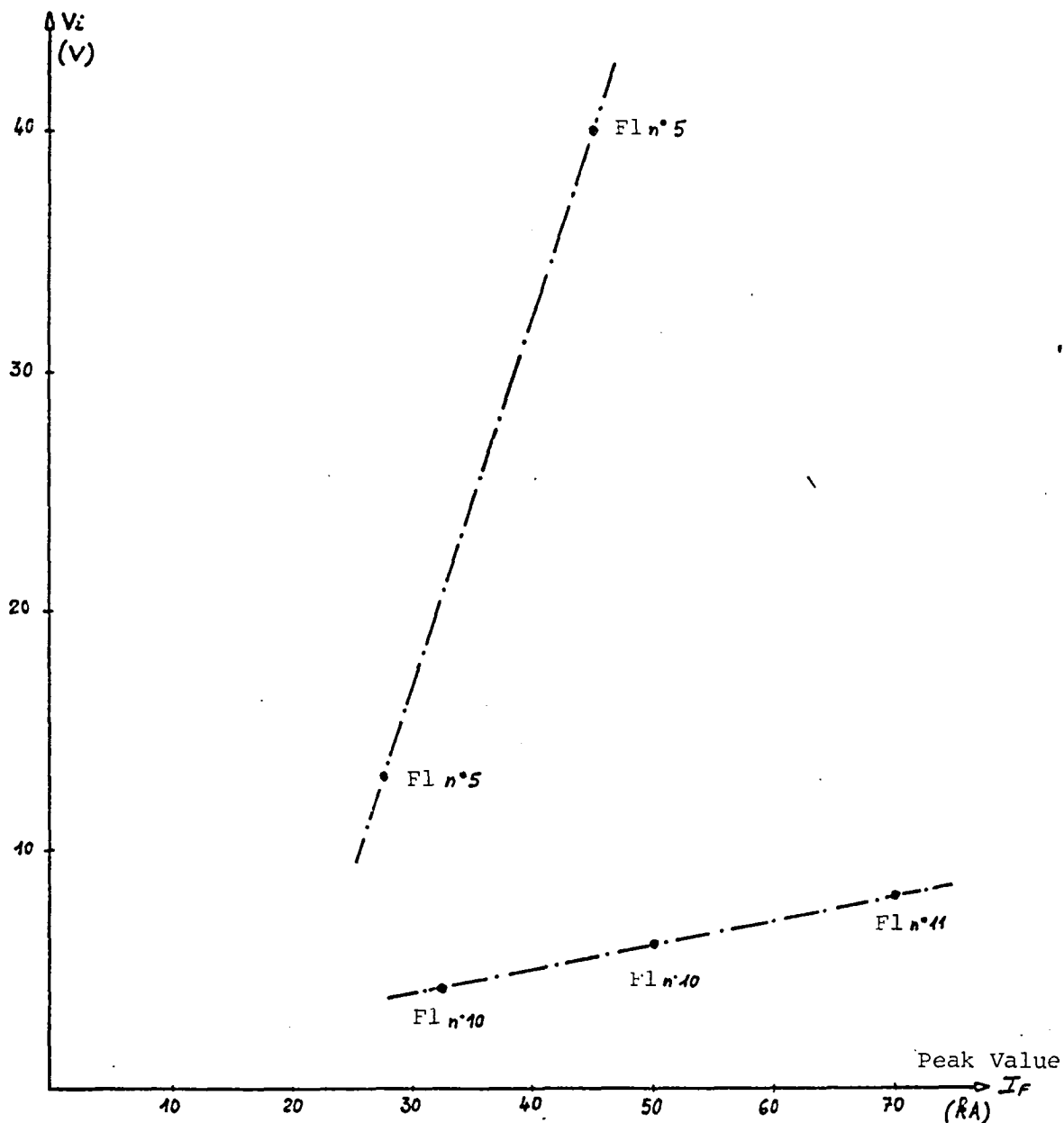
Remarks:



Comparison of Front Rod Lightning
Current with Test Line Voltage

..... Lightning Bolt Current
_____ Induced Voltage V_i

Plate 51



Voltage V_i Induced on the Test
Line as a Function of the Peak
Value of Lightning Bolt Current I_F

